MATERIALS AND CONSTRUCTION

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A TEXT-BOOK OF ELEMENTARY STRUCTURAL DESIGN

BY

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PREFACE.

The purpose in compiling this text and set of problems has been to present such studies in the elementary laws of construction as will give the student an understanding of the more simple formulas, and ability to apply such to every-day practice. The work is so arranged that it is available after the student period is past, as a hand-book of the necessary formulas, and principles of constructive details, which one must keep fresh in the mind when deciding on sizes and elements to be used in a certain kind of construction. It will be noticed that no attempt has been made to cover any advanced engineering work, the aim being rather to offer such material as is essential to the proper training of the young mechanic, or to the person aiming to become an assistant to the superintendent; the work is thus seen to be available as very good preparatory material.

The problems hold very closely to the practical; all those presented for design work are such as have come to the author's notice in one way or another, during an experience in engineering work covering fifteen years. The outcome of association and relations with young men just leaving school indicates that they have great difficulty in properly analyzing structures for the purpose of applying formulas taken in student work to actual construction. It is true no less in the

study of materials than in other subjects, that if the student meets the complicated details of actual construction in his problems, and has the guidance of a capable and careful teacher, he will get a satisfactory understanding of the subject in hand, and one of value in all practical work.

The formulas given for solution of problems coming under reinforced concrete are taken for the most part from "Concrete"[1] by Edward Godfrey, M. Am. Soc. C. E. These formulas were first presented by Mr. Godfrey in *Engineering News*, being quite thoroughly discussed, both favorably and otherwise, all of which discussion appears in the book mentioned. The formulas are notable for their simplicity; at the same time they point one to a definite result to be obtained which is an important factor for the beginner. The author has compared the formulas presented, with others of much more complicated arrangement and the difference in results is comparatively small. In dealing with this material we must keep in mind the fact that work is being done in an element which does not lend itself to refined calculations, and for which we have at best only very unsatisfactory formulas, if results obtained by their use are expected to check up with experiment. Paper No. 1250[2] by Gaetano Lanza, M. Am. Soc. M. E., is interesting and should be carefully read by teachers handling this subject with classes.

Throughout the work the principles should be brought out by the teacher, in the solution of problems before the class.

[1] Published by Edward Godfrey, Monongahela Bank Bldg., Pittsburg, Pa.
[2] Published by Am. Soc. M. E., 29 West 39th Street, New York.

Attention is called to the figures, used as illustrations, which in many cases were made from free hand sketches. The purpose in such a plan was to put before the student just the kind of a sketch which he will often receive, and from which his superior expects him to work without taking any time to make a finished drawing, developing his analysis from the figures given rather than by means of the related parts of a plan as they appear on a working drawing. Such a method is quite common in some plants where at times very sizable pieces of work are constructed entirely from sketches. The illustrations used have purposely been made rather large, so that figured dimensions, and letters may be clear.

If the book is used in a trade school, where the building and manufacturing classes are in different sections, the text is so arranged that certain features may be omitted without breaking the continuity of the work; for example, the building classes would not take those features applying to fixture design, or gear teeth, in strictly trade work. Looking at the text it will be seen that this can be omitted, and no general feature of structural work must be sacrificed in so doing. Throughout the book credit is given to authors from whose works tables and notes are taken; much material is presented from the writer's notes gathered at various times, from many sources, and the many technical papers must receive a portion of credit. Special thanks are extended to Mr. George W. Bartlett, Ph. B., for notes given the author while under the direction of this gentleman as a cadet engineer. Attention of the teacher is directed to the résumé of notation at the

close of the book, which saves the time of looking through the text, when a particular formula is taken up, for the purpose of determining the application of the letters introduced in the formula construction.

J. A. P.

WILLIAMSON SCHOOL.

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MATERIALS AND CONSTRUCTION.

CHAPTER I.

ELEMENTARY PRINCIPLES.

All structures which are met in practical work sustain a load of some sort, and if properly designed they are safe. Some structures are designed with care, that is, the load which will come on each part is calculated, and the part proportioned for this weight; in other cases the work is put up simply by judgment, the man who is putting it up has either built so much work of the kind, or made enough calculations so that design in detail is unnecessary.

This latter is the method commonly used in putting up scaffold or small hoists used about a building or factory; when, however, a floor is to be designed to carry a certain load, or a support for a tank is to be built, it is customary to make some calculations. If there are very large and heavy pieces of construction, the design is usually given to an engineer; when it is of the smaller order, and not complicated, some mechanic or foreman about the plant or operation will do what designing is necessary. This latter is the class of work to which we will devote our attention, viz.: The design of smaller pieces of work about the plant or operation, which are not sufficiently complicated to make necessary the services of an engineer but which

do require a knowledge of elementary structural work.

All structures sustain their load because of their power to resist breaking under it, and this resistance is offered in part by each piece which is used to build the construction. Again, each particle in each member must prove strong enough to sustain the load put upon it without being destroyed for further practical use.

Stress Defined.—The load on the structure of course is from without, while the power to sustain the load is within the members of the structure, so we see that an external or outward load is being sustained by an internal or inner power of the material forming the parts of the structure; when the members of any building are exerting such a power against an outward load they are said to be under a stress, from such a discussion we conclude that **"Stress is an inner resistance to an outer force."** Since all structures with which the mechanic deals are under a stress, he should be familiar with its development in a practical way as outlined above.

Any body which exerts a stress is changed in shape to a certain extent; this change may be so slight that we cannot detect it with the eye alone in many materials, but if a piece of soft steel or any other material which is capable of stretching considerably before it breaks is put in the testing machine and subjected to a heavy load, we can readily notice the difference in form.

Deformation.—This changing of shape due to loading is technically known as deformation.

In practical construction, of course, no appreciable deformation should be allowed.

Deformation is a general term applied to any kind

of change of shape; there are, however, different kinds of this change of shape, each having a particular technical name; *e.g.*, we take a rubber band and pull on it with the hands, it is readily seen to become longer; in strength of materials this particular deformation is called **elongation**. Again, if we take a sponge rubber and press it between the hands, it can readily be seen to grow shorter; this deformation is known as **"compression,"** and so on, each deformation being classified under the kind of stress producing it, as **torsional deformation** from a twisting force, **shearing deformation** from a shearing force.

Stress and strain are two terms often used to mean the same thing in practice as indicated under the definition of stress as given above. By some writers, however, "strain" is used in the sense implied by the term "deformation," as already defined; this same meaning is also much used by practical designers, so the young man may hear the word **strain** used to indicate either an external load, an internal resistance to that load, or a deformation.

As to the propriety of these uses we will not spend time in discussion; we simply have certain conditions of practice, and one should understand the possibility of varied meanings. In this book, however, they, as well as all other terms, will be used in the sense implied by the definitions.

Kinds of Stress.—There are five different kinds of stress as commonly classified; three of these are known as simple or direct stresses, while the other two are compound stresses; from this statement we conclude that **simple stress** is the effect of a direct action in such

a manner that only one kind of stress is produced on the piece loaded; we will find that

Tension: caused by a load which tends to pull apart.

Compression: caused by a load which tends to push together,. and

Shear: caused by a load which tends to cut off; all produce such a simple stress.

Compound Stress.—When a load is placed in the center of a beam, which is supported at each end, we do not find the beam subject either to tension, compression or shear *alone*, but all three are present; the shear is considered as a direct stress, in practical problems, but the bending effect is producing what is technically known as a **compound** stress. This is made up of both a tensile and compressive stress as we shall see by analysis later, hence it cannot be classified as a simple stress, because more than one kind of effect is created by the action of the load.

A torsional stress, that created by twisting, is another compound stress, composed of a combination of shearing and tensile stresses.

Stress Units.—In practical work as well as in experiments, it is necessary to have some definite relation between the load applied and the area of the member sustaining it. The area of elements used in structures is usually taken on a surface perpendicular to a line running lengthwise through their center; thus in fig. 1 we have a view of a simple structural or building form known in the trade as an I-beam. The line A.B. is its center line, known technically as its **longitudinal axis,** and if we cut the beam off on a line such as C.D. looking at the end pieces cut, they will appear as at

1*a*; and wherever we cut the beam, if we do so perpendicular to the line A.B., we will get a figure looking like fig. 2 anywhere in the length of the beam; such a

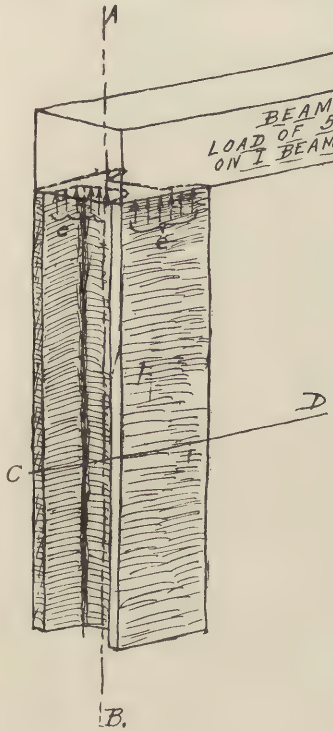


FIG. 1.

FIG. 2.

figure is known as the **transverse section,** and the area of it is known as the **transverse sectional area** of the beam. If the area of a section at any one point in the length of the beam, or other element, is the same as that found when the section area is taken at all other

points in its length, the piece is said to be of **uniform sectional area.**

In making calculations dealing with materials, a unit of area must be used for purposes of reference; this unit, under our system of measurement, is the square inch; suppose now that on the end of the upright I-beam, as shown in fig. 1, there rests a beam which causes a load of 5000 lbs. to be thrown on it; if we are using an upright I-beam having a sectional area of 5 sq. ins. then for each sq. in. sectional area of I-beam there will be $\frac{5000}{5}$ or 1000 lbs. of load, and each sq. inch of beam is stressed to this amount, which is known as the **stress per unit area.** *If then we divide the total load in lbs. on an element by the area of the element in sq. ins. we have the stress per unit area which is being exerted.*

It should be kept carefully in mind, from this point on, that the **unit area is the square inch** (commonly indicated thus: □″) and the **unit load is the pound** (indicated thus, #). The same method holds for determining stress per unit area in all three of the classes of simple or direct stress. If put in the shape of a word formula we have for determining stress the following: $\frac{\text{Total load in \#}}{\text{Total area subject to load}} = \text{Stress per unit}$ area, which formula may be applied in tension, compression or shear. We will find the above formula quite valuable in the study of practical problems since, if we look it over, we note the following:

Total load in # = Total area subject to load × stress per unit area

also

$$\frac{\text{Total load in \#}}{\text{Stress per unit area}} = \text{Total area subject to load.}$$

Elasticity.—The application of a load to an element deforms it to a certain extent as already mentioned; if the load is not too great, when it is removed the piece will return to its original shape; this property of materials—namely, returning to a first shape—after having been deformed is known as *elasticity*, and is possessed to a greater or less degree by all bodies. Assuming that we continue to increase the load, we will eventually find a weight which will deform the piece so much that no return to original shape will take place. In this process of loading, if we had our material where we could accurately measure both loads and deformations, we would find that as the loads were increased, the deformation would increase in the same ratio; that is, suppose we apply a load of 1000# and we find that the piece of material has increased in length 1/16″; apply a load of 2000#, or 1000# more than the previous load, and we find that the piece has increased in length 1/8″, or for the additional 1000# it has increased 1/16″ again; that is, every 1000# added causes an increase of 1/16″ over previous total length; doubling the load here doubles the total amount of elongation; continuing to add loads of 1000# we will find that at some point instead of an increase of 1/16″ for the added load the piece stretches more than 1/16″, and another load of 1000# causes a still greater increase of length; if we had removed the load while an increase of 1/16″ for every 1000# load was in order, we would have

found the piece returning to its original shape; if, however, we had removed the load as soon as it was noticed that an added 1000# caused an added lengthening of more than 1/16″ we should have found that the piece of material would not have returned to its original shape; these are facts brought out in testing various materials. We conclude, then, that there is a certain limit to the elasticity of materials, and our conclusion is correct.

Elastic Limit.—The point at which the deformation of a material begins to increase more rapidly than the load is known as the elastic limit. In the discussion above, it was the point at which we first noticed that for an added load of 1000# the length increased more than 1/16″. The elastic limits have been determined approximately for many materials and Table 1 will serve as a guide; it should be kept in mind that different authors give varied values for the elastic limit, those given being presented as a safe average.

In the designing of structures, the allowable stress in material must always be a great deal less than the elastic limit, **about 1/3 for tension and about 1/9 for shear,** if the elastic limit is used as a basis for permissible load. Some designers are working on such a basis but the practice is not common, the reason, as one would infer, being that the elastic limit is not very closely determined.

Yield Point.—When the elastic limit is reached, the material does not immediately lose all power of resistance and give way, but continues to sustain additional weight without a very marked increase in deformation, though there is a small increase; this condition will

continue for a few additions of load, after which the material acts as though it had very little resistance, showing a very large deformation for each addition of load. At a point, usually not a great deal beyond the elastic limit, in steel, the specimen yields very readily to the load applied; the point where this yielding takes place is technically known as the **yield point** and in practice we often hear this term used. The International Association for Testing Materials specifies all structural steel as having a yield point of not less than **1/2 the strength of the steel,** measured in #□″.

Ultimate Strength.—After the loads stressing steel to its elastic limit, and further loading stresses to its yield point, it will still carry added weight though it may be stretching or crushing very rapidly; continually adding loads, however, will finally break the piece with which we are dealing; we have now placed such a load that the full strength of the material has been used; the load which causes breakage, or "failure" as it is more often termed, is known as the ultimate load, and the stress in #□″ exerted by the piece at the time of breaking is known as its **ultimate strength** per unit area. Table No. 2 gives the ultimate strength of the commonly used metals, and No. 3 that of the woods.

Resilience.—If we deform a piece of material to a certain extent within the elastic limit, and suddenly remove the weight causing the deformation, the piece will spring back a certain amount, exerting some force as it does so. A very common device known to all is the spring railway switch, much used on trolley tracks; the car passing in one direction opens the switch, com-

pressing the spring in so doing; as soon as the car passes, the spring closes the switch. The spring being compressed, a certain amount of work was done, which was given out again when the spring was allowed to act; this work which is done when a body is free to act after being deformed is technically known as **"resilience."**

Factor of Safety.—Our study of materials thus far should have brought to our attention the fact that a body may be variously loaded, but at a certain point it begins to change its shape to a dangerous degree; in putting up any kind of structure we must keep well within the limit of safety of the material of which the structure is built. *The ratio of the ultimate strength of a given material to the actual load in lbs.* gives the number of times which the load might be increased before the structure would be destroyed; for example, suppose we load a piece of yellow pine, one sq. in. sectional area, so that in tension it is exerting a stress of 1600#. Looking at the table of timber strength, we note that this wood has sustained a load of 13,000#, at which load it broke; if we apply the rule just mentioned we have

$$\frac{130}{16} = 8+$$

or the load could be increased more than eight times, before the piece would break. The number of times which the applied load might be increased gives an idea of just how safe the structure is, and is technically known as the **factor of safety.** The word formula for its value is:

$$\frac{\text{Ultimate Strength}}{\text{Actual load}} = \text{Factor of Safety.}$$

In using the Table No. 4 of factors of safety, it must be borne in mind that these are simply averages, different writers and designers not of necessity using them; each firm will usually advise one in this connection, but for general purposes those given will serve as a guide.

Dead and Live Loads.—It is not customary to use the same factor of safety in all structures, as much depends on the kind of work which we require of it; in designing tools about the machine shop, one would not use the same factor of safety as he would in designing a support for a large water tank; two general divisions of loading are recognized, the *dead load* and the *live load*. If a load is applied gradually, and remains steady, it is known as a dead load; for example, a store room usually carries a dead load, so classified, because articles are commonly put there and remain for some time, the whole load not being thrown on all at once, but the room is gradually filled by placing a few articles at a time; on the other hand, if a stand is designed on which a motor is supported, it will be subject to a live load, because of the comparatively sudden application and release of the same.

Load-producing Shocks.—In Table No. 4 will be noticed entries for factors of safety to be used on structures, subject to load-producing shocks; such a load is a variety of live load of a very severe nature, making necessary unusually large factors of safety. Drop hammers, heading machines, swedging machines, pile drivers, and certain types of conveying machinery come under this class, and their supports should be liberally proportioned.

NOTE.

Most of the problems presented are questions of design which have been presented to the author from time to time.

Answers are not given in all cases, but a sufficient number are given to serve as a guide to the student if the book is used for home study; it should be kept in mind that an exact numerical result is not the essential sought in the solution of a problem, but rather a familiarity with the methods of applying the information contained in the text to conditions of practice. In actual design two equally capable men may select slightly different sizes of stock to do the same work, hence the student should be certain that his laws have been properly applied, then select the nearest standard stock available, when he may rest assured that his design will successfully do its work.

The teacher's attention is called to the fact that many of the problems may be used for other questions than those asked; thus any problem which requires determination of reactions, may later be used for beam design work, and any such problems presented for steel and timber construction may also be used for practice in reinforced concrete.

PROBLEMS.

The ton is taken at 2000#.

1. Describe the effect of tension, compression and shear when applied to a piece of material.
2. Explain your understanding of the terms: Unit stress, deformation, elongation.
3. Some pieces of wrought iron which were being tested in tension, sustained loads as given in the table below; the diameter at the smallest part of the piece is given in the column opposite the load applied as the test progressed; calculate the unit stress on the smallest part of the rod, for each load.

Load.	Diam. at smallest part.
1000#	1/2″
1470#	1/2″
1960#	7/16″
2940#	3/8″

Ans. for entry No. 3. 13066 *or* 13000+ #□″

4. A second test similar in all features to that given in prob. 3 developed the following facts:

Load.	Diam. at smallest part.
6560#	.425″
7070#	.415″
7500#	.410″
7890#	.400″
8160#	.395″
8600#	.385″
8890#	.378″

What was unit stress in smallest part of rod under each loading?

Ans. for entry No. 7. 80090#□″

5. The diameter of a screw used in a jack is 2″; when in use a section of this screw is subject to a direct compressive load of 3 T. What unit stress is exerted by the screw?

Ans. 1910#□″

6. A brick pier, laid up in lime mortar, dimensions of which are 8″×4″, fails under a load of 32,000#. What is stress in pounds per sq. in. at time of failure?

Ans. 1000#□″

7. A brick pier 16″×8″, laid as mentioned in prob. 6, fails under a load of 25,6000#. What was unit stress in this case, at time of failure? *Ans.* 2000# □″

8. In testing some samples of brick in compression, it was found that they crushed under the loads mentioned

below; if a brick is 8 1/4″ long and 4″ wide, what was unit stress in each case at time of crushing?

Whole brick crushed under load of 4000#.
Half brick crushed under load of 3670#.

Ans. 222.7# □″

9. Average practice permits a load of 6 tons per sq. ft. to be placed on common red brick laid in lime mortar; under such conditions what load should be placed on an 8″×8″ pier? *Ans.* 5052.6#

10. In testing a piece of sand stone which was 4″ square, it completely failed under a load of 13,600# per sq. in. What was total load on block at time of failure?

Ans. 217600#

11. Two brick piers 12″×8″ of common red brick are laid up, the first in common lime mortar, the second in a mixture of lime mortar three parts, and Portland cement mortar one part. The first pier failed under a total load of 150,000#, and the second under a total load of 290,000#. How much greater, in pounds per sq. in., was pressure on second pier than on first at time of failure?

Ans. 1458.3# □″

12. A freight store house is supported on four piers of rubble masonry; the floor is to carry a total load of 75,000#. What should be the area of the piers? See Table No. 5 for allowable load on rubble.

Ans. 6.2 □ft

13. In the tension test of a piece of timber, which was 1″ wide and 1/2″ thick, loads of 1000#, 2000#, 3000#, 4000# and 5000# were applied. What was unit stress on section under each loading?

Ans. for 4000# *load.* 8000# □″

14. What is the stress per unit area at time of failure, if a piece of 8″×4″ timber shears off, across the grain, under a load of 96,000#?

Ans. 3000# □″

15. A total load of 40,000# was necessary to shear off a piece of timber 4″ × 2″, across the grain. What was unit stress at time of failure? *Ans.* 5000# □″

16. A piece of timber, 3″ × 2″, placed in double shear, along the grain, failed under a load of 7200#. What was unit stress at time of failure?

Ans. 600# □″

17. A piece of 4″ square poplar loaded in single shear across the grain, failed under a total load of 70,400#. What was unit stress at time of failure. *Ans.* 4400# □″

18. A piece of spruce 6″ × 4″ parted under a load of 7200#, acting with the grain; a piece of white pine 4″ square, under the same conditions failed under a load of 4000#, which wood sustained the greater load per sq. in. and how much?

Ans. Spruce; 50# □″

19. If the ultimate tensile strength of soft steel is 55,000# □″, what total load must be exerted when a threaded bolt the diameter of which at the bottom of the thread is .508″ is pulled apart?

Ans. 11110#

20. An engine cylinder weights three tons; it rests on four feet, each of which is 8″ square. Determine the unit stress on the face of the feet.

Ans. 23.4# □″

21. Upon investigation it is found that a section of a cast iron engine frame is subject to a tensile stress of 470,000#. If the section mentioned has an area of 485 □″, what is unit stress? *Ans.* 969+

22. (a) A shear used in cutting off machine steel is working on stock 3″ wide and 1/2″ thick; determine the total load necessary to cut this stock.
(b) Determine the same when the shear is running on 3/4″ round bars.

Ans. to (a) 105000#

23. A punch is running on machine steel 1/2″ thick, piercing holes 1″ diam. What total load must be applied to perform this operation. *Ans.* 109900#

24. If a press is running on machine steel, 1/16″ thick, and the perimeter of a piece being punched is 2″, what total load must be exerted in forcing the punch through the steel? *Ans.* 8750#

25. A press is running on open hearth machine steel washers 1/16″ thich, having a hole 1/4″ diam. and an outside diameter of 1/2″; at each stroke of the machine four washers are pierced and blanked. What is necessary load to force the punches through the steel? *Ans.* 41212+#

26. What load will be necessary to stress a piece of cast iron 3″×1″ in section, to the elastic limit, the test being made in tension? *Ans.* 13500#

27. In testing a piece of cast iron one square inch section area, if we find the following relation existing between load and elongation:

Load in pounds.	Elongation in inches.
1000	.010
2000	.020
3000	.030
4000	.040
5000	.050
6000	.060
7000	.078
8000	.105
9000	.120

plot a curve, presenting these figures graphically, and on this curve locate the elastic limit of the material tested.

28. In testing a bar of wrought iron, 1 □″ in area, if the relation between load and elongation is as given below, plot a curve showing this relation, and indicate the elastic limit of the material on the same:

Load in pounds.	Elongation in inches.
5,000	.025
10,000	.050
15,000	.075
20,000	.100
25,000	.125
30,000	.165
35,000	.210

29. A steel eye bolt 1 1/4″ diam. is to support a hoist; if we stress bolt to 1/5 of elastic limit, what load may be lifted?
Ans. 9516#

30. What load may be placed on a 3/4″ steel eye bolt, if it is stressed to the elastic limit? Diam. at bottom of thread on such a bolt. may be taken as .620″.
Ans. 11739#

31 A motor weighing 1600# is being lifted by means of a steel eye bolt; the diameter at bottom of thread of this eye bolt is 3/4″. To what portion of the elastic limit is the bolt being stressed? *Ans.* 1/10 (*Approximately*)

32. What load may be put on a brick pier laid in lime mortar, 8″×4″, if we use a factor of safety of 5? On a 16″×8″ pier? *Ans.* (*on* 8″×4″) 2.66 tons.

33. If a piece of round steel 1″ diam. is loaded in tension with 1600#, what is the factor of safety against breaking?
Ans. 24+

34. If a brick pier 16″×8″ is loaded with 25,6000#, what is factor of safety against crushing? Specify method of laying which you selected.
Ans. Portland cement mortar 1.04

35. In the design of a piece of conveying apparatus a load of two tons must be supported by means of an eyebolt, what diameter must this bolt be at the bottom of the thread?
Ans. .704 *O. H. Steel*

2

36. A motor weighing 1200# is to be hung from the ceiling by means of four bolts; working with a factor of safety of 10, what should be the diameter of these bolts, assuming that a belt pull of 200# must be added to above, making total load coming on bolts 1400#?
Ans. .300 (*at bottom of thread*). *For safety this will require a 1/2″ standard bolt.*

37. A tie rod on a crane supports in tension, a load of 5 T. If this rod is to be of soft steel, what must be its diameter?
Ans. .892 (*at bottom of thread*).

CHAPTER II.

MATERIALS.

Kinds of Materials Used.—The materials commonly used in constructive work are stone, gravel, brick, lime, cement, terra cotta, sand, concrete, timber, cast iron, malleable iron, wrought iron, steel and brass.

Each of these is used in various styles; stone is used as rip rap, when it is taken without much attention to size or shape, and dumped as filling to form a base for a footing; it is also used in the form of broken stone, which is rock after it has been run through a stone crusher; stone dust, the material obtained by sifting the broken stone after it comes from the crusher; none of the stone mentioned thus far is "laid up," that is, placed by hand in any particular order. Rip rap is simply dumped and leveled off; broken stone is used in the same way, if used alone, and if in concrete, it is mixed by volume with cement and sand. Beside the above classes, stone is *laid* with varying degrees of nicety in about the following order: Grouted, which is stone piled up, and a thin mixture of cement and sand run over it (mixture of cement and sand is commonly one of cement to one of sand by volume, and enough water added so the whole will run very freely); this is often used in foundations and is satisfactory for common work.

Rubble is work built up of stones, somewhat irreg-

ularly and roughly placed; the joints are made up with either lime or cement mortar and the only dressing

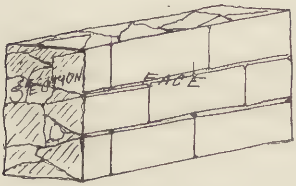


FIG. 3.—Coursed ashler with chamfered edges. Stones faced and laid to form joints or courses on the face, but backed up with common rubble; fig. shows face and section.

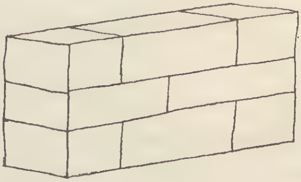


FIG. 4.—Dimension stone work; all stone cut to a specified size.

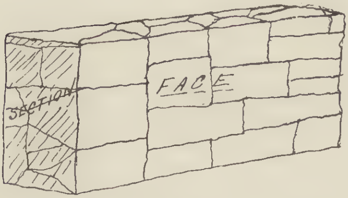


FIG. 5.—Broken ashler; jointed edges; stones of various sizes, faced and laid up in joint; backed with rubble; fig. shows face and section.

FIG. 6.—Random rubble; no work on stone other than breaking; it is the roughest laid stone work; not built in courses. As "coursed rubble" this same work is coursed on the face, but otherwise the same; fig. shows face and sectino.

done on such work is breaking with a hammer. **Ashler** is stone work having a dressed face; these styles of stone work are shown in figs. 3 to 6.

Trade Classifications.—In buying stone from the quarry it is designated as broken stone, rubble and dimension stone; broken stone, rip rap and rubble are usually sold by the ton, while dimension stone is purchased by the cubic foot. In ordering stone the size required relative to the purpose for which it is to be used must be kept in mind; this is particularly important in reinforced concrete work, where the steel rods used as reinforcement are laid across each other, and if stone too large in size is used in the concrete, it will not pass between the openings left by the reinforcing bars; this will be seen as a factor when the study of concrete footings is taken up. If an order is given for "run of crusher" broken stone, one may receive stone varying in size from 1/8″ to about 2 1/2″; this is satisfactory for the average small job, where no reinforcing is used; when a fairly uniform size of material is wanted it is customary to specify the size sieve through which it shall and shall not pass; a very satisfactory stone for general stock, and the average run of work, is specified as "passing through a 1 1/2″ sieve, but not through a 1″ sieve. **Rubble** may be ordered as "run of quarry" when one may expect to receive anything from the size of the fist, to fairly large sized boulders. The specification of the Chicago, Milwaukee and St. Paul Ry. for common rubble requires stone not less than 6″ thick, 16″ long, and 10″ wide, dimensions being approximate, and no dressing of the stone in any manner. **Rip-rap** calls for no stone less than 20# weight, and nothing larger than can be handled by one man. **Dimension stone** is ordered to the size required for any particular job.

Gravel is composed of small stones taken from sand banks, gravel pits, and earth; it may be ordered as run of bank, and will be assumed to include anything from a pebble 1/8″ to as large as the fist; if a uniform size is wanted, it, like broken stone, should specify sieve through which gravel must and must not pass. There are a great many tests of stone work prescribed for the engineer; only in comparatively few cases are they used, however, and though a knowledge of them is important to the engineer, it is not required of the mechanic, or man in charge of the field work, as a general rule.

Bricks.—There are many different kinds of brick, graded as to quality and shape; for the elementary study in materials we will deal only with those known as **common bricks** which are divided into 3 classes, according to their position in the kiln; originally they were known **only** by their position in the kiln while they were being burned; as different kinds of kilns are used in modern practice, this term relative to kiln position means less, and a classification as to hardness has become common; both methods of grading are given in the list following:

Arch bricks Hard bricks	Are the bricks nearest the fire burned very hard.
Red bricks Well-burned bricks	Are the best general purpose bricks; usually of a bright red color.
Salmon bricks Soft bricks	Are the bricks in the kiln farthest from the fire, and usually soft; used largely for filling in a wall.

Bricks are purchased by the thousand, and classified as above relative to quality. Brickwork should not be fully loaded directly upon its completion, because the mortar will be crushed out of the joints; it should be allowed to stand at least three or four days, before *any* load is placed, and full load should not be put on in less than from one to three months; if large factors of safety are employed, from 15 to 20, the full load may be put on in a month, and greater time should elapse as factors are reduced. These features do not affect the accupancy of a building as a rule, however, as the interior finishing and fitting usually require much more time than is necessary for the brickwork to set.

Lime, Sand, Cement.—Lime, sand and cement are used in mixing the mortars for constructive work; lime sells by the barrel or bushel; a barrel weighs **220#** (200# of lime and 20# for weight of barrel), and if purchased by the bushel, *two and one-half bushels weighing* 80# *each* are regarded as equal to one bbl. *Lime mortar* is mixed one part lime paste to two parts sand (though amount of sand is often increased to 2 1/2 or 3 parts, giving a weaker mortar, which is satisfactory for certain classes of work); lime paste is made by putting lime directly from the barrel or bag in a box which is fairly water tight and flooding with about two parts water, by weight, to one of lime. A barrel of lime should make about 8 cu. ft. of paste.

Sand.—Sand sells by the ton, and is classified as "pit" or "bank" sand, when it is taken from a sand bank, and as "bar" or "river" sand when it is taken from the sea shore, river beds, or shallow places in

water; sea sand should be washed thoroughly, but as this adds to the cost, it is frequently neglected.

Sieve Classification.—Sand should be screened before using; for common brickwork it may be run through a sieve having 16 meshes to the sq. in. (known as a No. 4 sieve, because it has 4 meshes per inch of length, and 4 per inch of width); for rubble work sand is not screened as a rule; if special requirements are made, a screen of 3/8″ mesh is often used. Occasionally one finds a locality where sand is sold by the load; a one-horse load is equal to about 22 cu. ft. while a two-horse is about 50 cu. ft.

Cement.—Cement is sold by the barrel or bag; four bags usually equal a barrel; there are a number of different grades, but the two general classes are Rosendale or natural cement, and Portland cement; these two terms refer to the method of manufacture, Portland being produced by a process different than that followed for Rosendale; this latter is commonly satisfactory for foundation work, but is not to be recommended for reinforced concrete.

Terra Cotta.—Terra cotta is a kind of brick, being much used in modern construction; it is very satisfactory as a fire proofing material, and is used a great deal for exterior finishing purposes in modern buildings; usually sold according to specification, the various forms being catalogued, the process of manufacture is one of forcing a plastic mass of clay, through or into a mold, and then baking; it is put on the market in dense, semi-porous, and porous varieties; the dense variety should be used in places where the work is exposed to much moisture, while porous and semi-

porous goods may be used in dry places. Nails may be driven in the porous varieties, which is an advantage when it is desired to set moldings, etc.; terra cotta should be loaded only in compression, and Table 5 gives values in this connection which may be used as a guide.

Concrete.—Concrete is really an artificial stone, made by mixing cement, sand and broken stone, cinders or gravel in the proper proportions; the single term **"aggregate"** is used to indicate the stone, gravel or cinders used in the mixture, hence when we hear the expression 1–2–4 concrete, it means one part cement, two parts sand, and four parts aggregate have been used to make the concrete mentioned. If the aggregate used is broken stone we have "stone concrete;" if gravel, it is spoken of as "gravel concrete," and if cinder, we know it as cinder concrete.

Mixing Concrete.—Concrete is mixed by hand on a board for small jobs, and by a mixer for large ones; most of that which is now being put up is known as **"slushed"** concrete; in mixing this it is just wet enough when mixed so that it will not remain in a pile, but runs slowly; this concrete is dumped into the forms set as described below, rammed with a rammer, and if smooth-face work is wanted, a shovel is worked up and down, next to the form, thus bringing the finer particles to the surface, and producing a satisfactory appearance when the form is removed.

Forms.—The forms used should be of heavy material, well braced; fig. 7 gives a general idea of a form set up for a wall and at A is shown the method of bracing; if the forms are made of 1″ stuff, such braces should

be about 18″ or 2 ft. apart, of 2″×4″ material; if the form is 1 1/2″ plank, distance between braces should be about 30″ and 2″×4″ stuff for braces; for rough work the forms need not be finished, but if a good appearance is desired, the boards should be planed on the side lying next to the concrete, and edges matched as shown in fig. 7 at M; spruce and hemlock are satis-

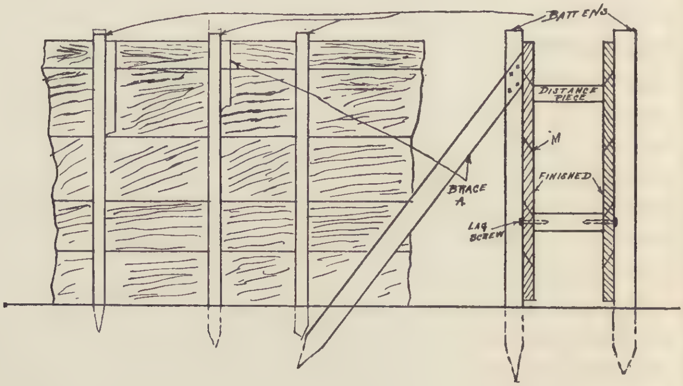


FIG. 7.

factory for such forms, though other lumber may be used; in setting, one face of form should be set plumb, true, and braced as shown in figure; distance pieces should be inserted as shown, so that the required thickness of wall is obtained, and the other form tied to the one set, by means of lag screws, passing through the form and into the distance pieces; such distance pieces should be placed about every 3 or 5 feet in height, between every pair of battens or braces. After the forms are filled, and concrete allowed to remain

about one or two weeks, all timber may be removed, the distance pieces driven out, and the holes filled with concrete, leaving a smooth wall; distance pieces may be about 2″ square.

In mixing concrete on a board the aggregate should first be thoroughly wet off the board separately, from the sand and cement; the sand and cement should then be thrown on the board in proper proportions, and thoroughly mixed in the dry state; the aggregate is then thrown in, and water added, the mass being constantly turned over and worked till the desired consistancy is obtained. If mixing is done with a machine, the materials are put into the mixer as measured, and about 6 gals. of water for each whole bag of cement is poured in; when mixing on a board the condition of the concrete can be observed, and water stopped when the required stiffness is obtained; in the mixer, however, all must be put in together; after a batch is run through, it should be looked over, and if too wet the water reduced, or increased if too dry; amount above mentioned gives a fair average for general work; in order that the concrete may be thoroughly mixed, the machine must run a specified length of time and the requirement of the National Board of Fire Underwriters is to the effect that the mixer shall make 25 complete revolutions.

Proportions of Ingredients in Concrete.—The amounts of materials used in concrete vary, but the following, taken from "Godfrey's Concrete,"[1] gives an idea of the proportions used in practice.

[1] Published by Edward Godfrey, Am. Soc. C. E., Monongahela Bank Building, Pittsburg, Pa.

Purpose.	Cement.	Sand.	Aggregate.
Walls and heavy work,	1	3	6
Reinforced concrete,	1	2	4

The aggregate suggested is broken stone or gravel; cinders, if clean, are a satisfactory aggregate for foundations of light buildings where great loads are not carried. Reinforced concrete is of sufficient importance to deserve a section by itself, and will be taken up as a later study.

Strength of Concrete.—In putting up concrete, it must be borne in mind that this material does not attain its full strength immediately, but should be allowed to stand from one to two months before it is loaded; the ultimate strengths given in Table 5 are for a cinder concrete 3 months old, of a careful mixture; no higher values are given because of unreliable conditions of mixing in practice, and inability to control to a nicety the placing in forms.

Timber.—Timber is used very extensively in all the trades; it is sold by the board foot; the patternmaker uses a great deal of white pine for pattern work, while in building construction hemlock, spruce, yellow pine, and oak are used. The strengths of the various woods are given in Table 3 and factors of safety in Table 4; lumber should be fairly free from knots and cracks for structural work, and is more satisfactory if well seasoned, since it is only about half as strong when wet as when dry, a fact to be kept in mind when using timber in constructive work, as it is not always possible to purchase seasoned material at short notice.

In selecting sizes to be used, one should choose a standard size of material, since such as do not come

within this class are sold at an advanced cost; fractional lengths should be avoided, and Table 6 is compiled to cover these requirements; if material 11 ft. long be ordered for a job, we will find it necessary to pay for that which is 12 ft. long, since this is the common practice on the market.

Grading of Lumber.—Lumber is graded according to specific trade terms, each of which has a distinct meaning on the market. "The standard classification of Yellow Pine Lumber" may be obtained at small cost from the secretary of the Yellow Pine Manufacturers Association at St. Louis, Mo. and the "Rules for Measurement and Inspection of Hardwood Lumber" from the National Hardwood Lumber Association, 1012 Rector Building, Chicago, Ill. A copy of each of these pamphlets, which are copyrighted, should be in the teacher's hand, who may give notes. Each student may obtain a copy at a cost of a few cents.

Metals.—Cast iron, wrought iron and steel are made from iron ore; the methods of manufacture are a very interesting and profitable series of studies in connection with the subject of chemistry; in this work only their application to structural work, of one sort or another, is taken up.

Cast Iron.—Cast iron is much used in the machine industry, the heavy beds and supporting parts of nearly all kinds of machines being made of this material; it is cast in the desired form by making a sand mold from a pattern, and pouring the iron which has has been melted into this mold; the work of the patternmaker is the making of the structure which is placed in the sand to form the proper shape of mold, that of

the molder is to place and remove this pattern so that he has a hollow shape, properly vented, into which iron may be poured in order to get a casting; this work of pouring also falls to the lot of the molder; the machinist does the necessary finishing of the casting, in order that it may serve its proper purpose in the design, cast iron is also used as beams, braces, etc., in building work. In the use of this material for shop purposes, as in jigs, fixtures, etc., it is common practice to make a few necessary calculations for the parts sustaining the greatest load, and design the remainder of the device from experience, and in relation to the requirements of each particular case; cast iron is not so convenient a material for design purposes as steel, because it is not put on the market in the same standard forms, with tables of properties published in hand books. Table No. 2 has entries giving ultimate strength of cast iron in tension, compression and shear.

Wrought Iron.—Wrought iron is used a great deal in forgings, but is not very common in structural work, average strengths given in Table No. 2.

Malleable Iron.—Malleable iron is a kind of cast iron; when first taken from the mold in the foundry it is very hard and brittle; it is treated by heating in an oven, this heat treatment being known as "annealing." After being subject to this process, castings in this material are quite strong, and permit of some bending, so are available for use in places where they are apt to be subject to bending slightly, or to shocks and more satisfactory results will be obtained than may be expected from ordinary cast iron, or gray iron, as the material coming directly from the foundry

is known. Malleable iron is produced from a pig iron of different variety than that used for gray iron, which is another reason beside that of foundry treatment, for its increased tensile strength. Table No. 2 gives values which will serve as a guide in using this material.

Steel.—Steel is produced from pig iron, which in turn is made from iron ore, by a number of different processes; it comes to the user as bar steel, sheet, and structural steel; bar stock is to be had in *rectangular*, *square*, *hexagon*, *octagon*, and *round* forms; as to material classification there are offered *open hearth*, *cold rolled*, *crucible*, and *tool steel.* Open hearth steel is a soft steel, commonly used for screws, bolts and general run of shop work; cold rolled is much used for shafting; crucible machine steel is used in machine construction for spindles, and similar work where a rigid reliable material is wanted for accurate work. Tool steel is a different material and as its name indicates is used for making tools; all cutting implements are made of some grade of this material, which can be hardened, and tempered; sheet steel, manufactured by the open hearth process, is used for tanks, drums, boilers, receivers, etc. Structural steel is rolled to a great variety of shapes; in designing, some one or more of these must be used, which are furnished as standards on the market; the tables of properties introduced in this work are largely from the Cambria Steel Co.'s hand-book[1] compiled by George E. Thackray, C. E., and are sufficient for the purpose which this book is intended to serve.

[1] Published by Cambria Steel Co., Johnstown, Pa.

Meaning of Terms used in Steel Manufacture.—The terms "open hearth," crucible, and Bessemer refer to different processes for making steel; they determine the three fundamental classifications of steel as used at the present time. Tool steel is a refinement of crucible steel, of which there are a great many grades, adapted to particular trade needs. The ultimate tensile strength in #□″ is given in Table No. 2 for several grades of steel; the ratio of compression and shear to the tensile strength may be taken the same as will be found by comparison of these stresses in Table No. 2; Bessemer, cold rolled, and open hearth are regarded as soft steels, while crucible and tool steels are regarded as hard steels.

In the use of all tables of strength given, it must be remembered that values are approximate; wide variations are often obtained in testing different samples of same materials, hence different authorities give varied quotations; again, the same class of materials put out by different manufacturers will differ widely, so that for general use one can but take an average, and depend on the factor of safety for a margin. The values of ultimate strength given in all tables are conservative.

QUESTIONS.

1. Describe rip-rap, rubble, and ashler.
2. What do you understand by the specification "run of crusher" stone?
3. Give your specification for gravel, assuming that you wanted stock the grains of which are between 1/4″ and 1/2″.
4. How are bricks classified? What is mortar and for what purpose is it used?

5. Write a brief composition, giving some information on stone, bricks, sand and cement.
6. A concrete wall 2 ft. thick and 6 ft. high is to be built; it must be smooth on both faces; give your specification for the concrete mixture, design the form complete, presenting sketches, and write out your directions for placing the concrete.
7. What is the general difference between malleable iron and cast or "gray" iron as you understand these materials?
8. Write a brief composition on the different kinds of steel.

CHAPTER III.

ELEMENTARY CALCULATIONS AND PROPERTIES.

If a wrench be placed on a nut and one pulls at the end of the wrench, the nut will be turned a certain amount; this effect of one's strength on the nut to turn it about a center, through the medium of a wrench, is known as the **moment** of that strength relative to the center of the piece on which the nut is placed; if we regard our strength exerted simply as a force, we have in the combination described a moment effect. In actual work we have many applications of this effect, which is carefully analyzed in both physics and mechanics; we will briefly study it for purposes of application in the use of materials.

Value of a Moment.—Assume that the wrench used was 12″=1 ft. long, and that a force of 15 lbs. was exerted on it; the *moment* of the force relative to the center is the *load multiplied by the length of the lever;* this result will not give a single value of lbs. or feet, but a combination of both pounds and feet, and the single unit for moment measure will obviously be the *pound foot* or the effect of one pound acting through a lever arm one foot long; following instructions given above to determine numerical value of the moment tending to turn the nut we have:

Load × Length of lever = Moment.
15# × 1 ft. = 15 lb. ft.

The word formula just given will enable us to determine any element of a moment combination, that is, load, lever arm, or moment, providing we know the other two because by inspection we see that:

$$\text{Load} = \frac{\text{Moment}}{\text{Length of arm}}$$

$$\text{Length of arm} = \frac{\text{Moment}}{\text{Load}}$$

If we apply these simple formulas to the problem we have just been studying it will be found that results balance; these principles apply the same when several forces act on a lever arm, as when but one acts, the total effective moment being equal to the sum of all the individual moments; to illustrate, suppose we have a windlass on which two men are pushing, one at the end of the bar, and the other 8 ft. from the center; the individual moments are (fig. 8) if a man can produce an effect of 15#:

$$\begin{aligned} 15 \times 12 &= 180 \text{ lb. ft.} \\ 15 \times 8 &= \underline{120} \text{ lb. ft.} \\ & 300 \text{ lb. ft. total moment.} \end{aligned}$$

Positive and Negative Moments.—Moments are classified as positive or negative, relative to their production of rotation in the same or opposite direction from the hands of a clock. Moments are said to be *positive* when they produce rotation, relative to their center of reference, in the same direction that the hands of a clock move; commonly known as "clockwise"; they are said to be negative when the rotation which may be produced is opposite to the above,

commonly known as "counter clockwise." A study of fig. 8 will make this clearer; suppose we have the same windlass mentioned above, with two men pushing on it, a little study shows us that the men who are pushing are creating a positive moment, because arrow K which indicates their direction of movement shows it to be the same as the hands of a clock, relative to center A. The load, however, creates a moment

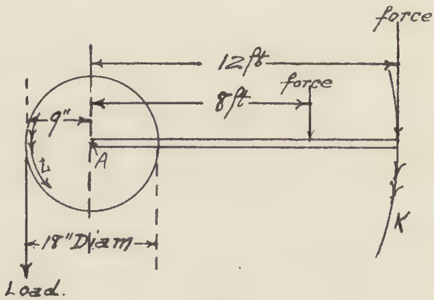


FIG. 8.

in a direction opposite the hands of a clock relative to center A, hence is negative. This principle, though simple, should be thoroughly mastered, as its analysis is sometimes confusing when applied to beam loading.

Beams and Methods of Loading.—There are two general types of beams used in elementary construction, the simple beam and the cantilever; if we put up a piece of construction as indicated in fig. 9, we have what is commonly known as a "bent"; the main members are two posts or columns, with a beam laid across them, the beam (known particularly

as a "header" in such a case) is fastened to the posts. Such a design is the simplest possible piece of building construction, and a beam supported in this manner is known as a **simple beam**; we are lead to define a simple beam, then, as **a beam supported at its ends only.** If we place on such a beam a load as indicated by the arrow A, it is spoken of as a **single concentrated** load; such a load would be imposed by a hoist attached to a beam; there may be several concentrated loads, but the general method of calculations for such loads does not differ, whether there be one or several, as

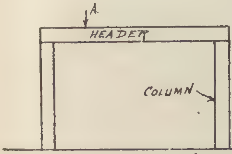


FIG. 9.

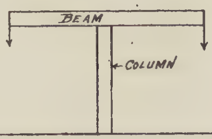


FIG. 9A.

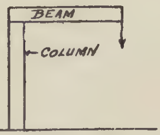


FIG. 9B.

will be seen later. If instead of loading with either single or several concentrated loads, a general load is applied evenly for the whole length of the beam, we have a **uniformly distributed load**; such a condition obtains when a joist supports a floor.

The unit used in connection with the uniformly distributed load is the **weight per foot of length**; *e.g.*, if a beam is 10 ft. long, and has a total uniform load of 2500#, then the load per ft. of length is $\frac{2500}{10} = 250\#$

The simple beam is of very common application in the trades, being subject to both uniform and concentrated loads.

Cantilevers.—A beam set as indicated in either 9*A* or *B* is known as a cantilever; such a beam may be loaded in the same ways as a simple beam; small cranes are very often built as cantilevers, and gear teeth are always considered as cantilevers.

Properties of Sections.—Before we can take up any actual calculations, dealing with the stresses in structural elements, we must study certain properties, of which we should have a working knowledge. Fig. 10 represents a beam sustaining a single concentrated load, and for clearness the load is represented as being

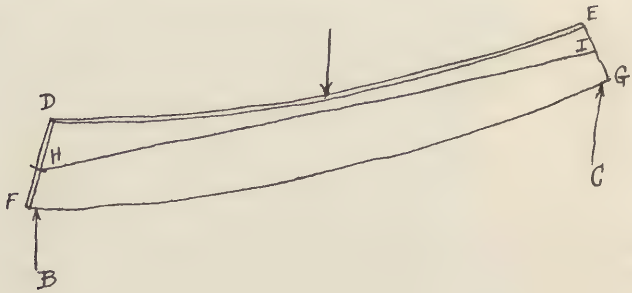


FIG. 10.

applied by a sharp-edged member, while the beam is being supported by two such sharp-edged posts. *In practice the center lines of the columns are treated in calculation as though they were such sharp-edged posts*, and dimensions for moments, etc., are taken from these center lines. The load on the beam causes a certain stress in the posts which support the beam; this stress of course is in a direction opposite to or against the load, hence is technically known as a **reaction.**

Stresses in a Simple Beam.—When a beam is loaded as shown in fig. 10, the top face D. E. becomes shorter than it was originally, while the bottom face F. G. becomes longer; somewhere in the beam, however, is a line which neither becomes longer or shorter, but retains its original length, providing we do not exceed the elastic limit of the material used as a beam; such being the case the stress above this line, which does not change length, must be compression, since it tends

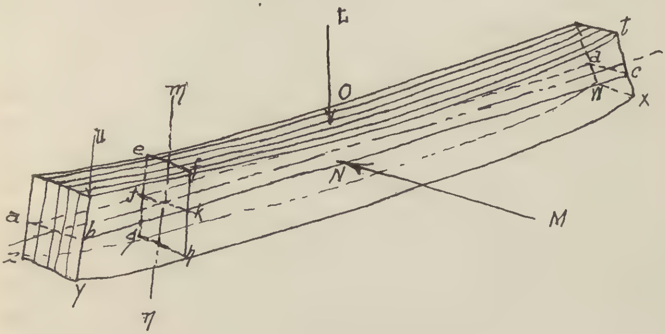


FIG. 11.

to shorten; below this line it must be tension, since it tends to lengthen. In addition to the above stresses of tension and compression, the beam is subject to a shearing action, tending to cut it off; such action is greatest at the supports, and when actual design is taken up we will find it necessary to make due allowance for it.

At the line which we are discussing as remaining of a fixed length, there must be neither tension nor compression, because if there were, the line must change.

so because it is not affected by the stress on either side of it we know it as the **neutral line** simply because it is not affected by the actions in the beam.

The beam we have been studying thus far is a very thin piece as is indicated by the figure; really it is not a beam but a thin section of material; if we put several such together, we will have a beam, rectangular in cross-section; each of these thin beams will have a neutral line, and several such neutral lines, of as many thin beams, form the **neutral plane** a-b-c-d, fig. 11, of the large beam; at *efhg* in fig. 11 is represented a section cut through the rectangular beam we have been studying; this section intersects the neutral surface in a line *J. K.* which is an axis of the section; and since it is an intersection with the beam neutral surface, it is known as the **neutral axis** of the section.

If we study the figure, we will question the necessity of the beam resting on the face *zyxw*, and the reason why it may not rest on the supports by means of the face *u. y. x. t.* will be sought; it may rest on either face, in fact a beam may be placed in any position desired, if it rests as shown in fig. 11, then *J. K.* is regarded as the neutral axis of the beam section; if we decide to let it rest on face *u. y. x. t.*, then the same process of reasoning, which we have applied, will indicate that *m. n.* will be the neutral axis of the section.

The axis used in calculation is always that one which lays perpendicular to the line of load. Thus in fig. 11, if the load is in a line parallel to *L. O.* we must deal with neutral axis *J. K.*, while if it is parallel to *M. N.* we will deal with neutral axis ***m. n.***

The location of the neutral axis for those shapes

most used is given in hand-books, and such as are needed for the work covered by this book are given in the tables of properties; it is necessary however to become acquainted with the method of its determination and so we will study briefly the process of neutral axis location for those common shapes which are most used; for practical purposes we may consider the neu-

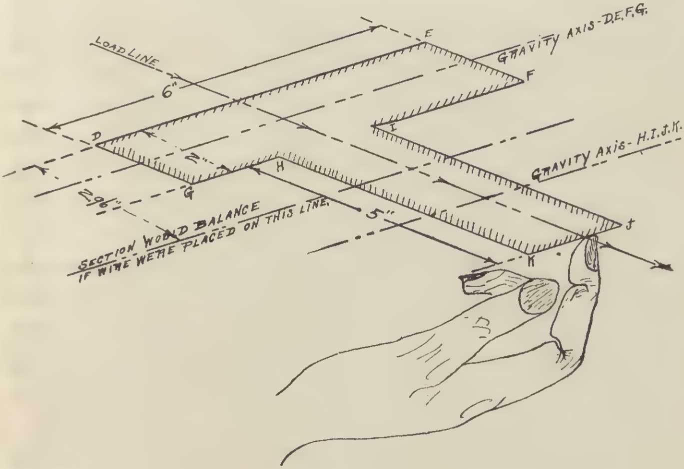


FIG. 12.

tral axis the same as the gravity axis, and hence if we find the center of gravity and pass a line through it perpendicular to the load line and in the plane of the section we have the location of the neutral axis. We will assume the section cut from cardboard and strung by one of the edges, which is parallel to the gravity axis we wish to locate, to a wire, let this edge be

D. E. fig. 12. Now as long as we hold the cardboard up with the finger it will remain in place, but when the finger is removed, the piece will swing down and simpy hang on the wire; if the wire were strung through the gravity axis, the cardboard section would just balance on the wire; to find out where the line is which allows the cardboard to balance, we will divide the section into a number of small parts; we know by inspection that if we had a section *D. E. F. G.* its gravity axis would lay half way between the two edes, and if we have a card like *H. I. J. K.* the same holds true; looking over the various parts which make up the whole section we are studying, we see that the gravity axis of *D. E. F. G.* is 1″ from the wire, while that of *H. I. J. K.* is 4 1/2″ (2″ + 2 1/2″) from the wire; now this cardboard has weight, proportional to its area, being the same thickness throughout, hence we may use the area as weight for the calculation of moments. From our previous study of moments we may deduce the fact that the moment of the combined area *D. E. J. K. G. D.* about the wire is the same as the sum of the moments of the elementary areas added together; the only thing we do not know is the lever arm of this combined area relative to the wire; since the sum of the elementary moments must equal the moment of the whole area, and as we have both weights and lever arms of elementary areas, we may easily solve for the distance from the wire at which the weight of the whole area acts as follows:

$$\left[\begin{pmatrix}\text{Elementary}\\ \text{area}\\ DEFG\end{pmatrix} \text{ times } \begin{pmatrix}\text{its lever}\\ \text{arm}\end{pmatrix}\right] + \left[\begin{pmatrix}\text{elementary}\\ \text{area}\\ HIJK\end{pmatrix} \text{ times } \begin{pmatrix}\text{its lever}\\ \text{arm}\end{pmatrix}\right] =$$

$$[(6 \times 2) \quad \times \quad (1'')] \quad + \quad [(5 \times 3) \quad \times \quad (4.5'')] =$$

$$\text{Total area, times, lever arm of total area}$$

$$27 \quad \times \quad \text{unknown}$$

making these calculations we have

$$[(12 \times 1(] + [(15 \times 4.5)] = 27x$$
$$\text{or}$$
$$x = 2.96''$$

The distance from the wire at which the whole weight of the area acts is 2.96″; we also have as a truth in mechanics the fact that the whole weight of any section will act through its center of gravity, hence the line 2.96″ from the wire is the gravity axis relative to the edge of the section with which we are dealing, and corresponds to the distance from the neutral axis to the outer face of the beam, or distance from **neutra axis to outer fiber** as it is technically termed; this distance will be represented in the formulas we will use by "*c*," and when the neutral axis is not equally distant from both faces of a section, the greater distance is used as the value of "*c*."

The same method outlined above may be applied to the location of the gravity axis relative to any one of the section edges; if it be used relative to *K. J.*, we will get the same result as already found (*Q. E. D.*, using other edges, and various sections shown in fig. 13). The various forms shown in fig. 13 are classified as follows:

A is a T section

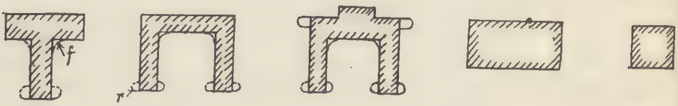
B is a channel section.

C is a channel section with rib.

The dotted lines indicate the manner in which the

designer enlarges the outer parts of the piece, and reinforces the corners to prevent breakage, but he does not consider these additions when finding gravity axis, simply using the block form as indicated by the full lines.

Moment of Inertia.—This is one of the properties of constructive elements which must enter into all calculations of strength when a beam or column is under consideration; the study of this property is taken up at length in mechanics, but our use of it in this work



A B C

FIG. 13.

will be as a factor in determining strength of elements; Table No. 7 presents formulas for determining the moment of inertia of the commonly used sections, and may be used for calculating the numerical value of various sizes and shapes, when such claculation is found necessary. The dot and dash line indicates the position of the neutral axis, relative to which the formulas apply.

Rectangular Moment of Inertia.—When the moment of inertia is taken relative to an axis (neutral axis), it is known as the rectangular moment of inertia and is represented in formulas by the capital letter (I). In actual work the designer does not calculate these values, unless he has no tables at hand which give such; the Cambria Steel Co. issues a hand-book con-

taining these entries, from which Tables 8 to 17 inc. are taken for the purposes of design covered by this work. In machine construction it may be desirable to use a size of section not listed among these standard forms since a casting, while it may be of channel, T or I section, might possibly not conform to the sizes listed, and in such a case one makes the necessary calculations himself by using formulas of Table 7.

Polar Moment of Inertia.—In the calculations for shafting it is necessary to use a moment of inertia relative to the **center** of the section, rather than relative to the neutral axis; wherever we are designing to sustain a twisting effect, rather than tension or compression, we use a polar moment of inertia, represented in formulas by I_p. These formulas are listed in Table 19. In using either I or I_p the fact must be kept in mind that the values are given in inches, *and all moments used in formulas introducing either of these must be in pound inches and not pound feet.* In the use of formulas for determining the strength of beams, the value obtained by *dividing the rectangular moment of inertia by the distance from the neutral axis to the outer fiber* $\frac{I}{c}$ is met with and is technically known as the **section modulus**; its introduction eliminates work as will be seen later when we take up design, due to making a direct calculation possible covering both "I" and "c." A study of the tables both of numerical values of properties and formulas for the same shows that this value is of common occurrence and provided for in such compilations; this value like I is always taken on the inch basis.

Fiber Stress.—A little thought in connection with our study of the neutral axis will lead us to the conclusion that at the neutral plane we will have no stress as it is under neither one nor the other of the two effective stresses acting; this is true, but as soon as we study the beam either above or below the neutral plane we will find an existing stress, and this stress becomes greater as we approach the top or bottom of the beam, until at the very top or bottom there exists the greatest stress found in any portion of the section, and it is for sustaining this greatest stress that the beam is designed; the term commonly used to indicate this stress in the portion of the section most distant from the neutral axis is **fiber stress**; it is commonly expressed in # per □″ and in designing its value should be taken from Tables 2 and 3 either tension or compression values being used, and introducing an appropriate factor of safety considering the kind of work which the structure will be called upon to do; this fiber stress will be represented in formulas by the capital letter (S_u).

Fiber stress value, tension, or compression.—If the material used as a beam or column is weaker in tension than in compression, the value S_u is taken for the ultimate strength in tension; if it is weaker in compression, our calculations will be based on the ultimate strength in compression, always designing the beam to sustain its load, when its smaller resisting power is considered.

Consideration of Moments in Beam Stress.—A. beam supports its loads by stresses exerted as moments, relative to its neutral axis as a center (except in case of the shear which we consider later). A careful study of fig.

14 will make this clear; let R_1 and R_2 represent the reactions coming to the beam, through knife edges; a portion of the length is removed, and a knife edge is inserted in place of the removed part, so that it seats on the neutral axis of the section; suppose we start to push up on R_1, we will find that section A will start to turn about the neutral axis, at N as a center; R_1 then has a lever arm about the neutral axis equal to L_1;

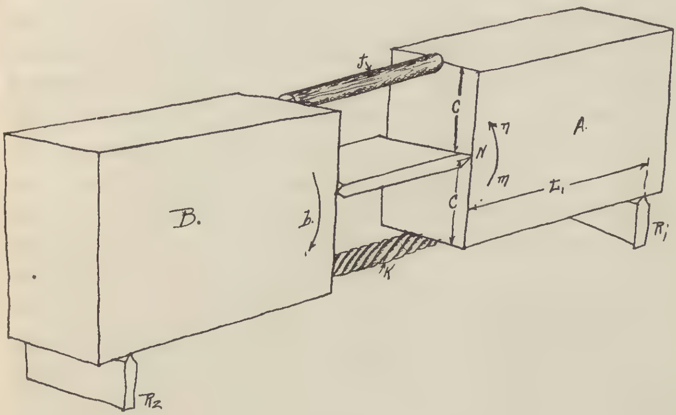


FIG. 14.

now of course a beam under such a condition could sustain practically no load, because the two ends A and B are not connected, and cannot resist the moment of the reactions, tending to turn it about the neutral axis; we will, however, put in an iron rod as at J, and a piece of rope as at K, drawing this latter up tightly; now when we start to raise at R_1 we find its moment resisted by the pressure of the iron bar, and

the pull of the rope, each having a lever arm, equal to c, and the whole beam will now turn about the other reaction point, that of R_2, as a center when we lift, instead of about the neutral axis; in other words, the beam will not turn about any point within itself. Now this is exactly what takes place when a beam is loaded, only the stresses in the fibers of the beam resist the moments caused by the reactions, instead of the bar and piece of rope.

Resisting Moment.—This moment created by the stress in the beam fibers, or fiber stress, acting relative to the neutral axis as a center is known as the **resisting moment** because it resists the moment created by the reactions, while the moment caused by the reaction is known as the **bending moment**. Now for a beam to even remain in place, *the resisting moment must equal the greatest possible bending moment;* if it is to be safe the *ultimate resisting moment must greatly exceed the maximum bending moment.*

Resisting Moment Formula.—A simple formula has been developed for evaluating the resisting moment, which given in word form is as follows:

$$\text{Resisting moment} = \frac{(\text{Safe fiber stress}) \times (\text{Rectangular moment of inertia})}{\text{Distance from neutral axis to outer fiber}}$$

Using the notation given below, this may be arranged in the form commonly met in beam design:

S_u = Safe fiber stress in $\# \square''$.

I = Rectangular moment of inertia.

c_u = Distance from neutral axis to outer beam fiber in inches. We then have:

$$\text{Resisting moment} = \frac{S_u I}{c_n} \qquad (1)$$

Studying formula (1) we see that it could take the form:

$$\text{Resisting moment} = S_u \frac{I}{c_n}$$

presenting directly the value of the section modulus, for which we may find it necessary to solve in future relations of this formula to the bending moment formula; at this time the formulas for determining section modulus, as well as the tables presenting this value, should be carefully studied as we shall find constant use for the resisting moment formula.

We have in this formula a means of determining the power of the beam to resist a moment created by an external loading and so long as such external load moment does not exceed the safe result for resisting moment, the beam is safe; to illustrate, suppose we wish to know the resisting moment which we may expect an I-beam 3″ deep, weight 5 1/2 lbs. per ft. to exert the web standing vertically when the beam is under load; from Table 8 we find the section modulus of this beam about axis 1–1 to be 1.7; for value of S_u we will look at Table No. 2 and find that soft steel has an ultimate tensile strength of 80,000# □″ and a compressive strength of about 2/3 of this or 53,000#; since the beam is weaker in compression we will use the latter value for S_u in resisting moment formula. We would not, however, load the beam to point of failure, but work under a factor of safety; we will assume a dead load, and take 3 as this factor, so the value of S_u

to be used is 17,000#; we recall the fact that both section modulus and fiber stress are based on the inch as a unit, hence when we determine numerical values, we will have a result in pound inches; our numerical values are:

$$\frac{I}{c_n} = 1.7$$

$S_u = 17{,}000$, so result becomes:

Resisting moment $= 17{,}000 \times 1.7$ or 28,900 lb. inches as the moment which we may expect this beam to safely resist.

The moment tending to bend the beam, as we have already seen, is created by the external load, and in order that we may understand the manner in which it is produced, we will study a very simple practical problem. Suppose the I-beam we have just been discussing supports a see-saw board such as is often seen in parks, playgrounds and amusement resorts, and two persons, one weighing 125 lbs. and the other 110# are on the board. The total weight of the two persons is 235# which is thrown on the beam 3 ft. from the left-hand support, according to Fig. 15, taking dimensions from center of support and board, which is the common practice for structural work of this class.

Determination of Reactions.—As long as any structure sustains a load, all parts of it are in equilibrium; this is true of the beam with which we are dealing in this problem; if a body is in equilibrium the algebraic sum of all stresses in it must be equal to 0, that is, all the forces up and down must balance; all the moments must

balance, and all shearing stresses must be balanced, the balancing effect of the elements forming the structure is due to their strength, while the loads cause the opposing forces. These facts must be kept in mind,

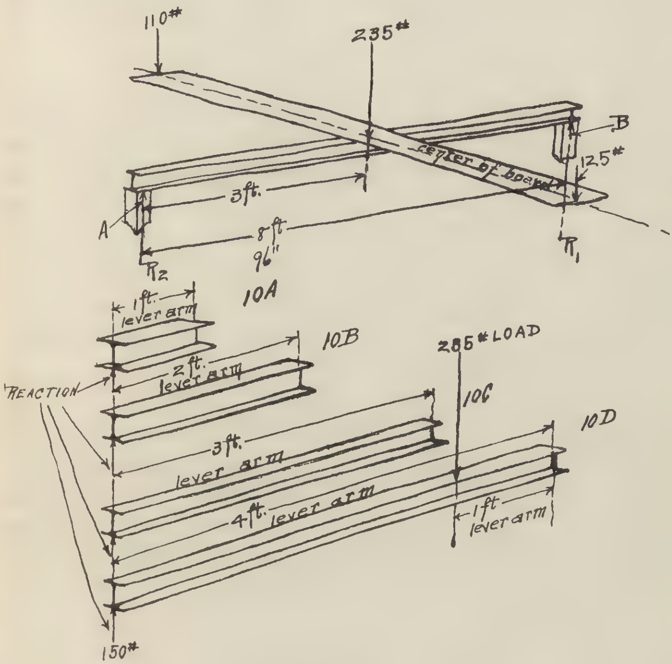


FIG. 15.

as we proceed with the study of reactions in beam work.

Looking at fig. 15 as illustrating the arrangements for a certain loading and method of support, for pur-

pose of determining reactions the point A is taken as a center of moments, and since we must fulfill the law of equilibrium in the effects of all moments acting on the beam, it is true that all moments caused by the loads must be balanced by the moment of the reaction; now by inspection of the figure we see that the moment of the load in this case is $3 \times 235 = 705\#$ ft.

We do not know the value of the reaction, but if we represent it by R_1 an inspection of the figure shows that its moment will be $8R_1$ ft. Now these two values of moments must be equal if the necessary laws are to be satisfied, and by arranging an equation, using the moments found, to meet this requirement we have:

$$3 \times 235 = 8R_1$$

Now the only unknown value here is R_1 or the right reaction, and a solution of the above equation will give the value we seek or

$$\frac{3 \times 325}{8} = R_1 = 88\ 1/8\#.$$

Thus we see that by an application of the principle of moments we are enabled to determine the reactions caused by a given loading on a beam. To determine R_2 we apply the same method, and have

$$5 \times 235 = 8R_2$$

or

$$\frac{5 \times 235}{8} = R_2 = 146\ 7/8\#.$$

Now if our reasoning has been correct, the sum of the loads should equal the sum of the reactions, since we recall the law that all the downward forces must be balanced by the upward forces and hence 235 must equal $88\ 1/8 + 146\ 7/8$; we note that such is a fact, and

the law of equilibrium has been satisfied; we also see that a load of 235# on the beam in the position indicated by the sketch, places a load of 88 1/8# on the right-hand support, and a load of 146 7/8# on the left-hand support.

QUESTIONS AND PROBLEMS.

1. Give your definition of the following terms: A simple beam; concentrated loads; cantilevers; uniform loads; simple moment (positive and negative); center of gravity; gravity axis; neutral axis; reaction; fiber stress, the difference between rectangular and polar moment of inertia, resisting moment.

2. If a man exerts a pull of twenty pounds on the end of a wrench, two feet from the center of a bolt which he wishes to turn, what moment is created?

   Ans; 480#″

3. Fig. 16 shows the construction of a drum and rope wheel as used on a hand hoist; what load can be lifted at the surface of the drum if a man exerts a pull of 25# on the rope?

   Ans. 120#

4. The area of a safety valve is 5 sq. ins. and is subject to a pressure of 100# sq. ins.; if this acts at a distance of 3″ from a center of moments, what distance from this center of moments must a weight of 20# be placed to balance the total pressure on the valve? *Ans.* 75″

5. In tightening a 1 1/4″ bolt on an armature a load of 80# was placed at a distance of 12 ft. from the center of the bolt; what moment in pound inches was created by this arrangement relative to the center of bolt?

   Ans. 11520#″

6. Looking at fig. 16, assume that a load of 1/2 ton is to be lifted from drum surface, what must be pull on the rope?

   Ans. 208#+

7. In fig. 17 is presented a diagram of the gearing of an ordinary contractor's winch. If a load of 1000# is to be lifted from drum surface, what load must be applied at the handle indicated by A? *Ans.* 18.5#

8. Suppose in figure 17 that we can apply but 10# at the handle, what load can be lifted from the drum surface? *Ans.* 540#

9. Looking at fig. 17, assume that we must lift a load of 1500# and can apply only 30# at the handle, the dimensions of gears G and E to remain unchanged; what must be the diameter of the drum D? *Ans.* 6.4″ (*would build this* 6″)

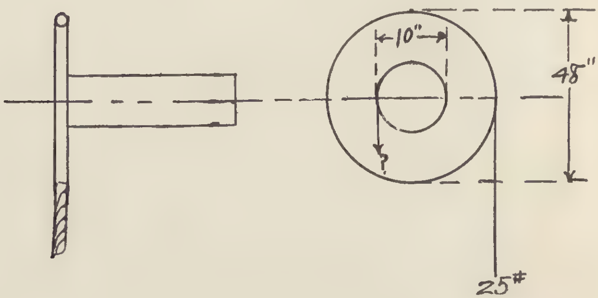


Fig. 16

10. Fig. 18 shows the dimensions of work and pulley on a lathe; if a pull of 200# is being exerted on the belt, what resistance in pounds is the tool offering? *Ans.* 933#

11. On a countershaft are placed a driving pulley 20″ diam. and a driven pulley 15″ diam.; if a pull of 156# comes to the circumference of the driven pulley, what pull must come to the circumference of the driving pulley to turn the shaft? *Ans.* *Not less than* 117#

12. If a simple beam 12 ft. between supports is loaded with

500# at a point 5 ft. from the left-hand support, what are the reactions? *Ans.* $R_1 = 208.3\#$ $R_2 = 291.5\#$

13. A temporary framework, built for the purpose of placing some machinery, consisted of two posts and a beam; the distance between post centers was 8 ft. and the hoist used was placed at 2 ft., 3 ft., and 5 ft. from the left-hand post in doing the work; the loads lifted were in all cases 2500#. What was the reaction in each case?

Ans. *At* 5 *ft.* $R_1 = 1562.5\#$ $R_2 = 937.5\#$

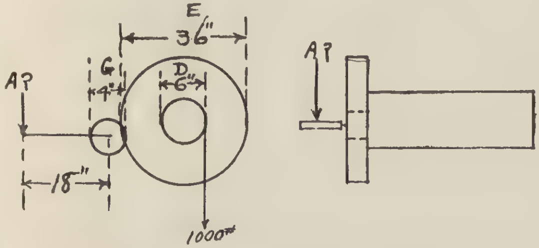


FIG. 17.

14. A beam in a building is 6 ft. between supports, and carries loads of 1500# at points 2 ft. and 3 1/2 ft. from the left-hand end. Determine reactions.

Ans. $R_1 = 1375\#$ $R_2 = 1625\#$

15. A lintel over a door is 4 ft. long, it carries a uniform load of 150# per ft. and a concentrated load of 2000#, 18″ from the right-hand end. What are the reactions?

Ans. $R_1 = 1050\#$ $R_2 = 1550\#$

16. If in the design of a piece of construction, the distance between supports of the beam is 15 ft. and a load of 500# is placed at 2 ft. from each end, and others of the same amount at 5 ft. and 7 ft. from left-hand end, what will be the reactions? *Ans.* $R_1 = 900$ $R_2 = 1100$

17. A tank support is so designed that six loads of one ton each are thrown on a beam 12 ft. long; the first load is 1 ft. from R. H. support and remaining loads are 15″ apart. Determine reactions. *Ans.* $R_1 = 7875\#$

18. A transformer stand carries three pieces of equipment, weighing 1000# each. The beams are 8 ft. long between supports which carry these, being so placed that each transformer throws a weight of 500# on each of two

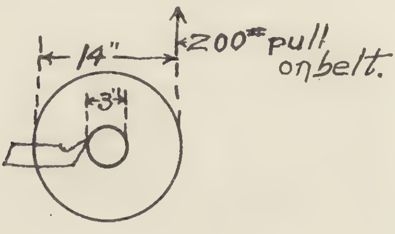


FIG. 18.

beams; the first load is 12″ from the left-hand support, the next 36″ from the first load, and the third is 12″ from the right-hand support; what are the reactions on each beam? *Ans.* $R_1 = 750\#$

19. In the design of a crane, it is decided to use a beam 20 ft. between supports; this beam carries three hoists which are located at 2 ft., 5 ft., and 15 ft. from left-hand support; when hoisting on a certain job, each hoist is lifting approximately 3000#; what are reactions.

Ans. $R_1 = 3300\#$

CHAPTER IV.

BEAM DESIGN.

Bending Moments.—We have now determined all the loads tending to bend the beam; we also know the greatest possible moment this size beam can resist. (See Resisting Moment.) Whether the actual moments created in the beam by the load and reactions are anywhere near the resisting moment, or whether the moment in some section of the beam caused by load and reactions is greater than its resisting moment we do not know; to decide this point of the relation as to value, between resisting moment and moment due to loading, we determine the greatest or maximum bending moment.

The method of determining this maximum bending moment is to calculate the moment values for several points along the beam, being sure that the position of any loads on the beam are used as points of calculation. These several points which we select along the beam are the moment centers relative to which we make calculations, and the lever arm used is the distance of any load or reaction from such a point; this should be taken in inches, as it will be necessary later in our work to have this value in pound inches rather than pound feet. Let us now determine the maximum bending moment created due to the loading of the beam, fig. 15;

centers of moments may start at the L. H. end, and be taken at 1 ft., 2 ft., 3 ft. (this is under the load), 4 ft., 5 ft., 6 ft.

To make clear just what is meant by "bending moment" let us study fig. 15*A*, and determine the moment created at a point 1 ft. from the L. H. end of the beam. The neutral axis is the center about which we make calculations, and the distance of the only force, the reaction, causing any tendency to turn about this point is 12″. To reduce to whole figures, a common practice in actual design, we will call the left reaction 150#. The moment then is

$$150 \times 12 = 1800\#''.$$

In calculating resisting moment, the center is the neutral axis; thus we see that the power of the beam to resist a load, and the effect of an external load on the beam, are both referred to the same line as a "center" when we are determining their relative values, thus giving a direct means of determining whether the load moment is greater than the resisting moment which the beam can offer, a condition which would indicate that the beam was unsafe. The **bending moment** *then is the moment of loads and reaction, calculated relative to the neutral axis of the beam section*, at definite distances from the L. H. end of the beam.

We will now continue the calculation of moments for the purpose of finding the greatest or maximum bending moment:

Second sec., at 2 ft. from L. H. end it is:

$$24 \times 150 = 3600$$

Third sec., at 3 ft. (under the load):

$$36 \times 150 = 5400$$

Fourth sec., at 4 ft. it is

$$(48\times 150)-(235\times 12)=4380$$

Fifth sec., at 5 ft. it is

$$(60\times 150)-(235\times 24)=3360.$$

We note by studying the cases of 4th and 5th sec. that the load causes a moment in a direction opposite to that caused by the reaction, so is subtracted from the reaction moment in determining the total bending moment. From the above calculations it is clear that the greatest bending moment is under the load, and it is a fact that this will usually be found true, in all cases the greatest bending moment falling under a load; in the case of several loads the process of calculation is necessary for the point under each load, in order to determine the greatest value.

If the beam is safe, the resisting moment, determined by the method already outlined, must be equal to or greater than the greatest bending moment; since the resisting moment was determined in pound inches, and we must compare the resisting and bending moment, we readily see the necessity for reducing the bending moment and resisting moments to the same terms, otherwise a comparison is of no value as a guide.

Comparison of Resisting and Bending Moment to determine Beam Safety.—The load on the beam is comparatively small and one of the lighter beams ought to be sufficiently strong; we have no certainty in this connection, however, until comparisons as just outlined have been made; looking on p. 50, we note that the resisting moment for a 3″ – 5 1/2# beam, the smallest given in our table, is 28,900 # ins.; looking on p. 58, we note that the greatest bending moment is only 5400#

ins., so that as a matter of fact, the smallest beam rolled is much stronger than is really necessary, for the loads we have been considering. We will study this same piece of construction later, however, when the need of the size steel beam selected will be shown.

Shear in Beams.—The bending moment is not the only feature to be considered, however, when we design a beam, since the load may possibly cut the beam off at certain places, so the matter of shear must be given study; in advanced work dealing with materials the effect of shear is interestingly developed, and the results obtained which we will use in the present study; *the greatest shearing stress developed in a beam will be at the support* and it is *equal to the reaction.* If we deal with more than one reaction, the larger value should be the one on which we base our calculations. In the problem we are studying, the reactions are not equal, hence we will introduce the greater value in our calculations; looking on p. 52, we find this reaction to equal 146 7/8#, according to our own calculation. We will use the value of 150# in our consideration of shear, however; this is the total load tending to cut the beam off at the support. The ultimate strength of soft steel in shear is 70,000# per sq. in. according to Table No. 2, and if we use a factor of safety of 3, it is safe to put a shearing load of 23,000+# □″ on this material; in the table of properties we find that the area of the beam we selected was 1.6 □″ hence we may load in shear to $23{,}000 \times 1.6 = 36{,}500$#; our actual load, however, is but 150#, so the matter of shear in this case need give us no concern.

Shear not Evenly Distributed over Whole Section.—In

a careful study of this stress, however, it is found that it is not evenly distributed over the whole section of the member, but is greater in some portions than in others; in fact, the *maximum shear in a cross-section of a rectangular beam is* 1 1/2 *times as great as would be the case if the total shear* (150# in the case we have just been studying) *were uniformly distributed.* In cases where the shear due to the load nearly equals the strength of the beam in shear, this feature should be considered; to cover such a detail when using I-beams, Z bars, channels, or any of the usual rolled shapes, it is customary to regard the *webs only as sustaining shear*, and assume the stress uniformly distributed over the web. Where the possible applied load in shear is so much greater than the actual load as we found in the case just studied, there is no necessity for making further shear calculations.

Beam Design.—We have covered the complete process in design of a simple beam, carrying a single concentrated load, making a study of the various elements and relations, entering the problem, so can now take up the work of beam design in general, and as met in practice; let us make a study of the construction in practice, which has served our purpose in gaining a knowledge of the necessary elements: In the design of playground equipment a "see-saw" rack is to be covered: What size steel I-beam should be used as a support for the seat board, assuming the construction as shown in fig. 19, if it be supposed that two men, weighing 150#, sit on each end of all the boards?

There will be 150# on each end of the board, or 300# coming on the beam at each board center; applying

former principles we have, if R_1 represents right reaction and R_2 left reaction:

$$10R_1 = (300 \times 8) + (300 \times 5) + (300 \times 2) \ \ldots$$
$$10R_1 = 2400 + 1500 + 600 = 4500$$
$$R_1 = \frac{4500}{10} \text{ or } 450\#.$$

Subtracting this value from our total applied load of 900# we have:

$$R_2 = 450\#.$$

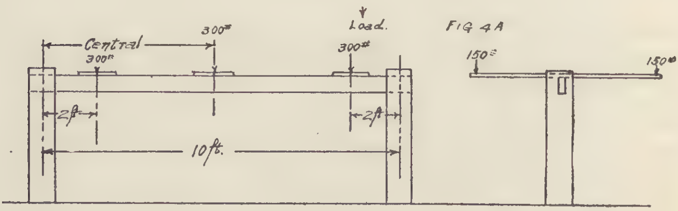


FIG. 19.

To determine the maximum bending moment we will make calculations under each load: Under first load from left support the bending moment is:

$$450 \times 24 = 10{,}800\#''.$$

Under second load it is:

$$(450 \times 60) - (300 \times 36) = 16{,}200\#''.$$

Under third load it is:

$$(450 \times 96) - (300 \times 72) - (300 \times 36) = 10{,}800\#''.$$

The maximum bending moment is under the middle load, and from previous calculations we know that the resisting moment of a 3″ light I-beam is 28,900#″, so it is perfectly safe; also our shear is only 450#, so the beam may be used, and the designer still has a wide

margin for any unusual load, or extremely rough usage, to which this class of structure is often subject.

It will be noted that the method for finding the bending moment in cases where there are several concentrated loads, as well as the reactions is in no way different from that used when dealing with one concentrated load.

It will be much more convenient in our work to have our formulas in letter form rather than word, and as familiarity with the various properties is developed reference to the proper letter as found in the notation will be made, and all formulas requiring the value will be made up with the letter. A moment is always indicated by M with a subscript indicating the particular moment to be dealt with; to illustrate:

M_s is a simple moment.
M_b is a bending moment.
M_B is a maximum bending moment, see Table No. 20A.

Uniformly Loaded Beams.—When a beam is used to support a floor, the load does not come to one point but is evenly distributed over the whole length; this class of loading is known as *uniform* loading, which means that each foot of length of the beam sustains a certain number of pounds, this number of pounds being the same for each successive foot.

In designing beams carrying a uniform load the same formula for resisting moment is applied as in the case of a concentrated load, but the formula for the maximum bending is different, being developed algebraically, so the necessity for taking several points along the beam to determine the greatest bending moment does

not arise. We will make no attempt to derive this formula, since its evaluation may be taken up in mathematics with more profit, giving the following as a result:

$$M_B = 1/8 P_t L_i$$
$$P_t = \text{Total load on beam in lbs.}$$
$$L_i = \text{Length of beam in inches.}$$

The same reasoning as applied previously will make clear the fact that to be safe the resisting moment must at least equal the maximum bending moment, so we will have

$$S_u \frac{I}{c_n} = 1/8\ P_t L_i \qquad (1)$$

S_u = Safe unit stress in #□″

I = Moment of inertia.

c_n = Distance from neutral axis to outer fiber of beam.

As an illustration we may calculate the maximum bending moment developed in the floor joist of an ordinary piece of flooring mentioned in the following: When putting up an addition to a stock room, it is found that a uniform load of 3000# comes on a floor joist which is 12 ft. long between centers of supports. Select the proper size yellow pine stick for the job.

Looking at Table No. 3 we see that yellow pine is weaker in compression than tension, and our design will be based on compression for this reason; this room will be subject to a dead load, and if we use a factor of safety of seven, a fiber stress of 1200#□″ may be permitted. The numerical values for the various elements to be introduced in this problem are:

$S_u = 1200$

$I = \dfrac{bh^3}{12}$ (See Table 8.)

$P_t = 3000\#$

$L_1 = 144$ (Length of beam in ins.)

$c_n = \dfrac{h}{2}$ (The neutral axis of this section is at the center, hence distance to outer fiber is $1/2\ h$.)

Introducing these values we have

$$1200\frac{\frac{bh^3}{12}}{\frac{h}{2}} = 1/8 \times 3000 \times 144$$

or

$$1200\frac{\overset{bh^2}{\cancel{bh^3}}}{\underset{6}{\cancel{12}}} \times \frac{2}{\cancel{h}} = 1/8 \times 3000 \times 144 = 54000$$

or

$$1200\ bh^2 = 6 \times 54000$$

and

$$bh^2 = \frac{6 \times 54000}{1200} = 270$$

b and h are both unknown; this could be solved mathematically, but in practice it is more simple to solve by substitution, that is, look at Table 6 where we have listed the standard sizes to be found on the market and introduce their various values until the width and thickness when multiplied together balance the result as just found:

We will first try 2×4; here $b = 2''$ and $h = 4''$.

$2 \times 16 = 32$, much less than 270, let us try 2×12
$12^2 = 144$, hence

bh^2 in this case is $2 \times 144 = 288$, so 2×12 is satisfactory.

This joist will of course be laid on edge; a point to be mentioned now is the fact that a deep narrow beam is a better selection than a square beam, hence in making your choice of material hold to the policy of applying a relatively deep beam or stick rather than a square one, as this leads to economy of construction as well as good design.

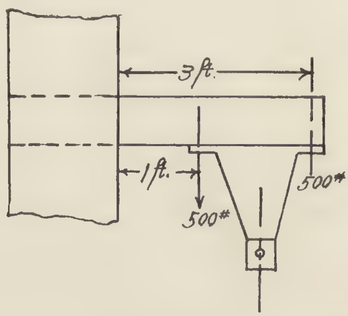


FIG. 20.

If we were designing a steel shape to do this work, the numerical value of the section modulus could be taken directly from the tables presenting properties of the various shapes.

Cantilevers.—Cantilevers have been defined previously, and the design of this type of beam involves no new principle; we must deal with the resisting moment and maximum bending moment related to each other in the same manner as previous cases have demanded.

The formula for the resisting moment is of exactly the same form in all types of beams, whether we plan to use steel, iron or wood; those for the maximum bending moments are as follows:

$$M_B = P_c L_i + P_c' L_i', \text{ etc.} \tag{2}$$

P_c, P_c', etc., representing the various concentrated loads, while L_i, L_i', etc., represent the distances of these various loads from the wall or support.

For a uniformly loaded cantilever the formula is:

$$M_B = \tfrac{1}{2} P_t L_i \tag{3}$$

Design of Cantilever.—As an illustration of the application of cantilever formulas the following example of a piece of construction may be used: A piece of yellow pine timber is used as a cantilever to support a shaft hanger, shown in fig. 20; select proper size.

Looking at the figure we note that two loads are thrown on the cantilever, one 3 ft. from the wall, the other 1 ft. from wall; a case of a cantilever loaded with two concentrated loads and formula 2 will apply in determining the maximum bending moment; numerical values to be introduced are:

$P_{c_1} = 500\#$, load nearest end.
$P_c = 500\#$, next load nearer wall.
$L_1 = 36''$, distance of extreme load from wall.
$L'_1 = 12''$, distance of next load from wall.

The formula for resisting moment is unchanged, viz.:

$$S_u \frac{I}{c_n} = M_B.$$

Looking at Table 3, we see that the material is weaker

in compression than tension, and under a factor of safety of 7 we may impose a unit stress of 1200#□″, so that:

$$S_u = 1200$$

and from our Table No. 8 we find that the section modulus is:

$$\frac{bh^2}{6}$$

Introducing all numerical values in No. 2 we now have, recalling that for safety the resisting moment must be at least equal to the maximum bending moment:

$$1200\frac{bh^2}{6} = (500 \times 36) + (500 \times 12)$$

making calculations we have

$$bh^2 = 120.$$

Looking at our standard size list we see that 2×8 will meet the requirements.

If instead of concentrated loads we had have met with a uniform load on the beam, rather than equate the resisting moment to formula 2, in the design, we would have used formula 3, the remainder of the work being unchanged. A glance at the shearing strength of yellow pine across grain, shows us that we need not consider this feature, as there is a wide margin of safety.

QUESTIONS AND PROBLEMS.

NOTE.—Any of these problems are available as beam design problems; select proper beam to carry the given load.

1. If a beam 4 ft. long between supports carries a load of one

ton at the center, calculate the bending moment 1 ft. and 2 1/2 ft., from left-hand support.

Ans. At $2\frac{1}{2}$ *ft.* 18000#"

2. A beam which is 12 ft. long carries one load of 2500# 4 1/2 ft. from left-hand end and another load of 3400# 7 1/2 ft. from the left-hand end. Determine bending moments at 4 1/2 ft., 6 ft. and 8 ft. from left-hand end.

Ans. At 8ft. 12250# *ft.*

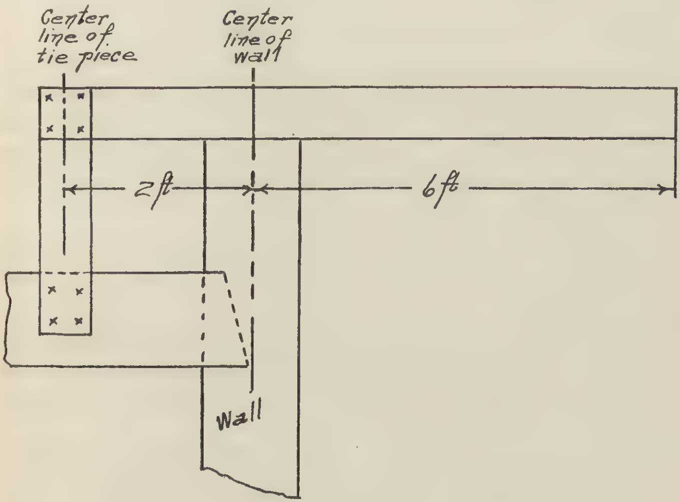


FIG. 21.

3. A beam 12 ft. long carries a load of 600# 5 ft. from the left-hand end. What is bending moment at middle of length? *Ans.* 1500# *ft.*

4. A cantilever used for hoisting purposes is built in a wall, the hook by which the hoist is attached is 4 ft. from the wall face; the maximum load to be lifted is 2500#. What is bending moment at wall when this load is being hoisted?

Ans. 10000# *ft.*

5. The same arrangement shown in fig. 21 is often used as a support for a scaffold. If the section outside the wall (6 ft.,) must support 100# per ft. of length, what will be bending moment at the center line of wall?

Ans. 1800# *ft.*

6. A water tank is supported by means of two cantilevers; this tank is 4 ft. diam. and 6 ft. long, the cantilevers are 4 ft. long, and the tank is so placed that cantilevers are uniformly loaded; what is bending moment at wall (cu. ft. water taken as 62.5#) when tank is full of water.

Ans. 4710# *ft.*

7. A small engine is supported by means of two cantilevers, each cantilever is 42″ long, and a load of 125# is thrown on it at a point one foot from wall, while another 125# load is concentrated three feet from wall. What is bending moment at wall? *Ans.* 500# *ft.*

8. A cantilever 2 ft. from face of wall to the end is loaded with a uniform load of 500#. What is bending moment at wall face? *Ans.* 500# *ft.*

9. In the design of a railroad hoisting tower a cantilever six feet long carries two loads of 500# each, one being at the end, the other 2 ft. from the end. What is bending moment at wall? 2 ft. from wall?

Ans. 2 ft. from wall 3000# *ft.*

Note.—Cantilever lengths are commonly taken from the face of the wall.

CHAPTER V.

COLUMNS.

Whenever a post is used, the length of which is more than ten times its diameter, the member is classified as a column; such a piece fails or breaks in quite a different manner from a piece, the length of which is not more than ten times its diameter, and hence the design is based on different formulas. In the design of short blocks it is necessary to take into consideration only the compressive load per unit area, such load not exceeding a certain safe value based on the ultimate crushing resistance of the material used, covered by a factor of safety.

In the consideration of columns, however, the fiber stress in tension or compression must be taken up, as well as the properties of sections used in the column. In practice we see platforms supported on columns; the footstock spindle of a lathe is a column; the piston rod of an engine, the screw in a jack, and long clamping screws sometimes introduced in jigs all fall under the same headings.

The manner in which tension or compression is produced is presented in fig. 22. Suppose we have a concentrated load on the end of the column, and bending begins to take place; such bending puts the piece used as a column in the same relation concerning

stress as we met in the beam, viz., compression on one side and tension of the other; we also see that the column will bend in the direction of the lesser dimension; from this we deduce a general truth to the effect that square or round stock should be used as columns rather than rectangular. This is not a *fixed* policy, as diagonal bracing may greatly modify selections, but should serve as a guide in general.

FIG. 22.

Column Formula.—There are a number of different formulas used in column design, each giving good results, but for the work in mind, Rankine's formula is the most satisfactory because it can be applied to many different kinds of work, with fairly satisfactory results. The use of this formula will introduce to us another new term, known as the **radius of gyration**; this property may be calculated for the sections commonly used in practice, by means of the formulas given in Table No. 7, it will be noticed that the formula presents a factor termed the square of the *least* radius of gyration; since this property is determined from a formula using the moment of inertia, and since the value of the moment of inertia may vary, depending on the axis of reference, it is evident that we may find more than one numerical value for the radius of gyration; the smallest value of the radius of gyration should be used in making column calculations because such a member is most apt to bend

relative to its lesser dimension. The radius of gyration equals the moment of inertia divided by the sectional area, or the formula may be used as follows:

$$r = \frac{I}{A} \qquad (4)$$

r indicating the radius of gyration.
I the moment of inertia.
A the section area of the member.

Like the other properties discussed, however, the calculation for the various shapes, while an interesting mathematical problem, requires too much time if it can possibly be avoided, hence the most used forms are tabulated (see Tables 9 to 17) for use in actual design work, and constant reference will be made to these in working the various problems.

Classification of Columns.—Columns are classified according to the end construction, because this feature affects their strength to a certain degree; these classifications are as follows:

First.—Flat ends: A column of this construction is one on which the ends are fixed; the posts supporting floors, or shop platforms are of this class.

Second.—Round end: A column of this class is free to turn in any direction at the ends; as such in the full sense of the definition, this column is seldom found in practice; the connecting rods on all machinery however fall nominally under this class, as they are free to turn at the ends in one direction but not in others, so a formula for round end is used for the dimension lying in the direction of turning, and one for square end in

determining the dimension lying parallel to the direction in which the column cannot turn at the ends. A case of this kind with which all are familiar is the connecting rod on a locomotive.

Third.—The pin and square end: A column fixed at one end but free to turn at the other. A boring bar comes under this head as also do some forms of jack screws.

As to the method of deciding whether a column falls under a certain class the student may be guided as follows: If the piece is *rigidly fixed at both ends* it may be treated in practice as a *square-end column*. If free to turn in any direction at the ends it should be regarded as a round-end column, in determining dimensions lying parallel to direction of turning, and for other dimensions as a square-end column; if it may turn in any direction, that is, not fastened by means of bolts or rivets, or held in position in any manner, it should be regarded as full round end. If a column is fixed at one end by means of bolts, screws, or any kind of fastening, while the other end is not fastened in any manner, the element would fall under the *pin and square classification*. So we see that in order for a column to be calculated as a round-end column, it is not necessary that the ends be round; these ends may actually be square, but if a beam or load simply rests on them, there is nothing at the junction in the form of bolts or rivets to prevent turning, hence the element is treated as round end, so the decision is based on the method of building the joint in a large measure.

Column Formulas any Formula Notation.

P_c = Safe load in lbs.
A = Area of column section in sq. ins.
S_u = Safe load in lb. per sq. in. on the material used in the column.
1 = Unity.
B = A constant to be introduced for columns of various materials see table 18.
L_i = Length of column in inches.
r = Radius of gyration.
For values of B see Table 10.

$$P_c = \frac{AS_u}{1 + B\frac{L^2_i}{r^2}}$$

(A) is the formula for safe load on square-end columns.

$$P_c = \frac{AS_u}{1 + \frac{16}{9}B\frac{L^2_i}{r^2}}$$

(B) is the formula for pin and square columns.

$$P_c = \frac{AS_u}{1 + 4B\frac{L^2_i}{r^2}}$$

(C) is the formula for round-end columns.

Eccentric Loading of Columns.—Thus far we have considered only those columns which carry a load directly on the end, a case where there is an even distribution over the whole section area of the column, and the formulas studied apply to columns loaded only

in such a manner. Many cases arise in practice, however, in which a whole or part of the load comes on a bracket, either cast or riveted on the column as indicated in fig. 23 where we notice one load coming directly on the end of the column, while another is thrown on a bracket attached to the column; such a load, being out

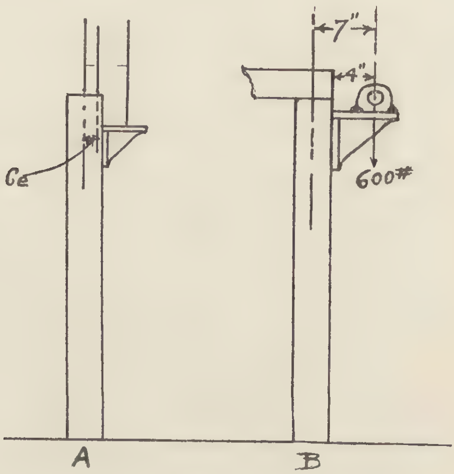


FIG. 23.

of line with the center of the column, is known as an *eccentric load*, and the column is said to be eccentrically loaded; the formulas previously studied do not apply to problems involving eccentric load, but in their stead, the following are used:

Formulas and Notation for Eccentric Loading of Columns.—P_m = Total load coming on column, both direct and eccentric.

$d =$ Distance of resultant of direct and eccentric load from center of column.
$A =$ Area of section of column in sq. ins.
$c_n =$ Distance from center of column to outer fiber.
$S_u =$ Safe unit stress on material in lbs. per sq. in.

$$S_u = \frac{P_m}{A} + \frac{(P_m d) c_n}{I} \qquad (5)$$

The solution is usually for A by the method of substitution, as will be noted in the illustrative problems below; again S_u is not taken as the direct safe compressive stress which may be put on the material but must be calculated by use of the following formula:

$$S_u = S_k - \left(\frac{S_k}{100} \times \frac{\text{Length of col. in inches}}{\text{Breadth or diam. in inches}}\right) \qquad (6)$$

The above is used for calculating S_u when the material is either timber, cast iron or concrete. S_k in this case is the safe fiber stress in direct tension or compression.

To determine the value S_u for steel shapes, which usually depart from the square, round, or rectangular form use the following formula:

$$S_u = 16000 - 70 \frac{L_i}{r} \qquad (7)$$

$L_i =$ Length of column in ins.
$r =$ Radius of gyration.

Position of Resultant of Two Parallel Forces.—The value d introduced in the formula for eccentric loading makes necessary the location of the resultant of two

parallel forces, that is the direct and the eccentric load. In amount the *resultant of two parallel loads equals the sum*, and to find its distance from the center of the column we use the following formula.

$$d = \frac{P_e B}{C} \text{ in which} \qquad (7)$$

d = Distance from center of column to point of action of resultant.

P_e = Eccentric load in lbs.

B = Distance from center of column to point of application of eccentric load.

C = Sum of direct and eccentric load.

d is measured off in the direction of the eccentric load. B in practice is taken as the distance from the center of the column to the center of the bracket supporting the eccentric load.

Application of Column Formulas.—In the design of a store room, it is found that a load of 5 tons will be thrown on a post which is 10 ft. long. The post is set in concrete at the foot, and spiked to the header which carries the load. Select the proper size Y. P. timber.

Since this column is set in concrete, and spiked above, it is fixed at both ends, hence we will use the square-end formula; looking at Table 3 we notice that yellow pine is weaker in compression than in tension, so we design on this stress as a basis; the store room will be subject to what is known as a dead load, so we may use a factor of safety of 7 (see Table 4).

We may now gather the numerical values for the solution of our problem as follows:

$P_c = $ 5T or 10000#
A To be found
$S_u = $ 1200#

$$B = \frac{1}{3000} \text{ See Table 18.}$$

$L_i = $ 10 ft. or 120″

$$r^2 = \frac{(\text{least side})^2}{12} \text{ To be found. See Table 7.}$$

Introducing these values in the formula for square end columns we have:

$$10000 = \frac{A \times 1200}{1 + \left(\frac{1}{3000} \times \frac{(120)^2}{\frac{(\text{least side})^2}{12}}\right)}$$

Working out the last term of the denominator we have

$$120^2 = 14400$$

$$\frac{1}{\underset{\underset{5}{\cancel{10}}}{\cancel{3000}}} \times \frac{\overset{46}{\cancel{14400}} \times \overset{6}{\cancel{12}}}{(\text{least side})^2} = \frac{276}{5 \times (\text{least side})^2}$$

5 will go into 276 about 55 times and will not seriously affect our results, as we will see later that we will have to use a "commercial size" varying somewhat from the actually calculated size, so we will make the cancellation for convenience, and we will have

$$10000 = \frac{A \times 1200}{1 + \frac{55}{(\text{least side})^2}}$$

In practical solution no effort is made to work this formula to determine unknown quantities, but different sizes are "tried out" the same as already mentioned in connection with beams; first let us try a 4″ sq. post and see if the equation will balance; if it does, then the following must be true:

$$10000 = \frac{16 \times 1200}{1 + \frac{55}{16}}$$

but when we work out the right-hand member of this equation we find that it equals something over 4000, much less than 10,000 which it should be; we conclude then that 4×4 is too small so we will try the next larger "commercial size" in square, see Table 6, which is $6'' \times 6''$, and the values then become

$$10000 = \frac{36 \times 1200}{1 + \frac{55}{36}} \quad \text{(A)}$$

and our right-hand member works out to about 17000, or more than 10,000, so 6×6 is satisfactory; a smaller post would serve, but if we purchase "out of standard" we must pay an extra price, which is usually more than the cost of a stick of standard size, which is somewhat larger than we really need.

The solution for any type of column studied thus

far is carried out in exactly the same manner as above, using the proper formula for end classification, providing there is no eccentric load.

The following problem will illustrate the method of solution for eccentric loading:

A piece of yellow pine is to be "built in" as described in the preceding problem, carrying a load composed of 10,000# direct from a header, and a bracket is bolted on, as shown in fig. 23, which carries a countershaft bearing, throwing a load of 600# on the bracket as shown; select the proper size timber.

First design the column as though it were carrying the *entire* load both *eccentric and direct* as a direct load, using the result thus obtained as a basis for the design of columns with eccentric load, and in the problems used as illustrations, such a plan will be followed.

The total load, *direct plus eccentric*, in the problem with which we are dealing is 10,000# + 600# = 10,600#, hence if, when the sizes of a selected stick are introduced in the right-hand member for safe load in formula A this member works up to a value of more than 10,600#, the piece is safe; we have already seen that a 6×6 works to more than this value in our illustration for a directly loaded column, so we may use a 6×6 as a basis for our work; since 6×6 is quite a little too large for the direct load, it is possible that it will be satisfactory for the case carrying the countershaft, so we will make calculations. First we must determine the value of S_u by use of formula No. 6. We used a safe direct compressive stress of 1200# in our first solution which is taken as the value S_k in formula 6, then

$$S_u = 1200 - \left(\frac{\cancel{1200}}{\cancel{100}} \times \frac{\overset{20}{\cancel{120}}}{\cancel{6}}\right) = 960\#$$

$120''$ = length of column, and $6''$ is its breadth; working this value we have $S_u = 960\#$ as the safe figure to be used in formula 5.

For numerical values in this formula we have:

$S_u = 960\#$
$P_m = 10600\#$
$A = 36''$
$d = .4$
$c = 3''$ half width of trial post
$I = \frac{bh^3}{12}$. See Table 8.

or $I = \frac{6 \times 6 \times 6 \times 6}{12} = 108.$

Introducing these values in formula 5 we have:

$$S_u = \frac{10600}{36} + \frac{10600 \times .4 \times 3}{108} = 420$$

as we see, we may have a value of 960 for S_u, it is evident that the 6×6 is amply safe, and we have a wide margin; as an exercise the 4×4 might be tried, and we will find that it is too small for the load imposed.

PROBLEMS.

1. A yellow pine post 10 ft. long is to carry a load of 5000#, determine its size; the post is solidly built in both at top and bottom.

Ans. 4×6

2. What size steel I-beam would you use to carry the load mentioned in prob. 1 under the same conditions?
Ans. 3″ *medium*

3. If a beam rests on two columns, 12 feet apart, such a beam carrying a total uniform load of 15,000#, what size steel I-beams may be used as columns to support this beam, such columns to be 12 ft. long and simply set on the footings, no fastenings being used at joints.
Ans. 7″ *light*

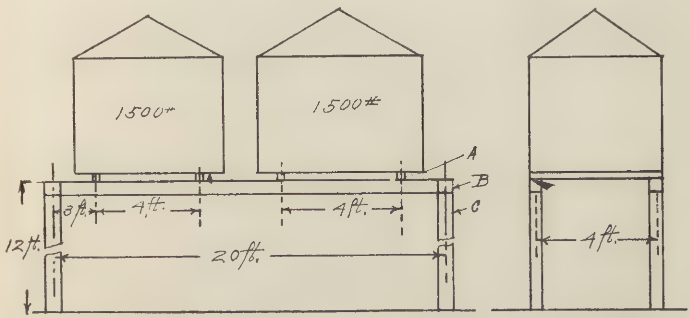


FIG. 24.

4. A bent is to be constructed; the header is to be 4 ft. between supports, and posts are to be 12 ft. long. A load of one ton is to be supported at the center; design steel columns.
Ans. 3″ *light*

5. A tank contains an amount of water which weighs 5000#; it is supported by means of brackets on four columns, which are 5 ft. in length. Select proper size timber for the column.
Ans. 4×4

6. Fig. 24 presents the construction of a transformer stand. Design the headers *B* and columns *C* all to be built of timber. Unless otherwise stated all joints are assumed to be solidly fastened.

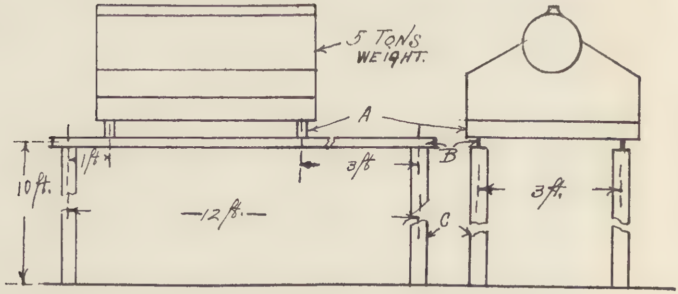


FIG. 25.

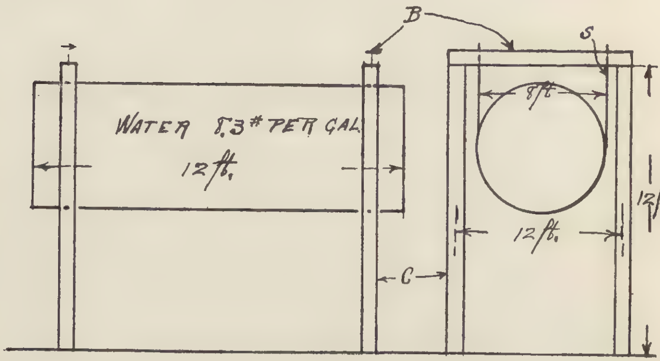


FIG. 26.

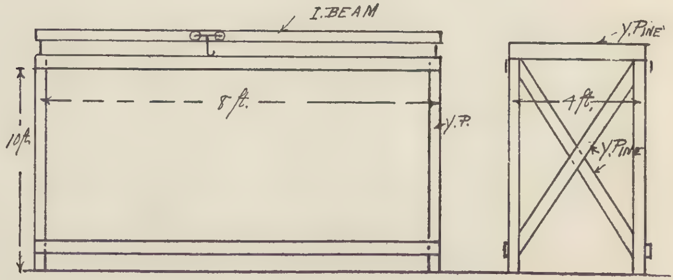


FIG. 27.

7. Fig. 25 shows the main supporting system for a plate bender. Design the cross-beams *A*, header *B* and columns *C*, the whole construction to be of steel.

8. Fig. 26 shows the construction used at the top of a building to support a water tank, which is to hold 3000 gals. Select the proper size slings *S*, columns *C*, and headers *B*, the entire construction to be of steel.

9. Design a support for a tank to carry 5000 gals. of water, presenting sketches showing the construction. It should meet the following specifications: Bottom of tank must be clear of floor 12 ft., supported by means of four columns, and the entire structure to be of steel.

10. Fig. 24 presents the desired construction for a movable shop crane. Select the proper sizes of various parts using materials indicated in the figure.

CHAPTER VI.

TORSION.

The greater portion of our work under this heading will have to do with shafting, and, as we shall see later, it is important in making calculations to know the number of revolutions per minute that a shaft makes; in some cases we may have to select the speed; Table No. 21 may be looked over at the beginning of this subject, and serve as a general guide in the solution of problems as well as in design.

When a shaft is subject to a twisting or torsional effect, there is created a shearing stress, within the element; a brief study of any body which is being twisted, as it is commonly expressed, will show that we have neither a case of tension nor compression as an elementary stress because in torsion the fiber is not pulled apart, nor pushed together, but, instead, the particles composing the piece slide by each other thus giving evidence of shear; hence the strength of the material under discussion, *in shear*, is the property on which formulas for torsional strength are based. Materials are subject to torsional stress in all kinds of shafting, and as such equipment is extensively used in manufacturing plants, the young mechanic should be familiar with calculations applied to its design.

The load applied to shafting is not commonly given

in pounds as has been the case with all of our previous work, but in horse-power, because shafting is used to transmit power, and the practical English unit for such is the horse-power; we must have in mind the fact, however, that a horse-power is but a certain number of pounds moved a number of feet, and this being true we readily see how and why it is preferable to state the load on shafting in horse-power if we study the following:

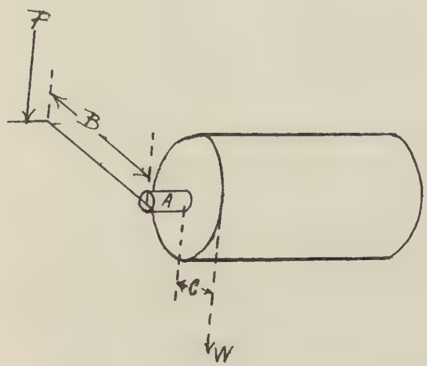


FIG. 28.

Fig. 28 represents a drum and shaft, with a handle, which may be used when properly supported to raise a weight; now the shaft A must transmit the necessary power to do the raising of the weight; we have here, then, a simple case of moments, in which the lever arm of the lifting power P is equal to B, taken in inches, and lever arm of load W is equal to the radius of the drum, also taken in inches, or C as shown on the sketch; the diameter of this drum is twice the radius or $2C$ and

circumference is $2\pi C$; if now we turn the drum once around we will move the weight upward a distance equal to its circumference, assuming the weight to be attached to the drum by means of a rope, or $2\pi C$ inches, and the work done will be equal to the weight, multiplied by the number of inches moved, or W times $2\pi C$ inch-pounds, that is, $W2\pi C$ in.-lbs. If instead of making but one revolution we turn the crank a number of times N the work will be equal to that found above multiplied by N or $NW2\pi C$ in.-lbs.

We recall the statement that the shaft must transmit all power necessary for lifting the load, and also the moment created by the load is WC; now in order to be safe the shaft must be able to resist this moment WC without breaking, so we have a case similar to the beam, in which an internal resisting moment of the shaft must be equal to or greater than the external moment of the load; the resisting moment of any shaft is determined by the use of the following formula:

$$\text{Resisting moment} = \frac{S_s I_p}{r_s} \qquad (8)$$

in which the following notation is used:

S_s = Safe shearing strength of material used as shaft in $\#\square''$.

I_p = Polar moment of inertia.

r_s = Radius of shaft in ins.

Since we have seen above that $NWC2\pi$ equals the amount of power necessary to move the load a certain distance, and if a shaft must transmit the power to move this load, and we also know that the shaft-resisting moment must equal the load moment, then

the introduction in the above formula of the value of the shaft-resisting moment for the load moment, will give us the amount of power in inch-pounds transmitted by the shaft in doing this work or

$$N\frac{S_s I_p}{r_s}2\pi = \text{inch-pounds of work.} \qquad (9)$$

The number of turns N of the shaft might be made in a minute or an hour, however, and yet the same number of inch-pounds of work would have been performed. To be definite, then, we must limit the number of turns to a certain period of time, and as we must measure in horse-power, this time unit will be the minute; one horse-power is equal to the performance of 396,000 inch-pounds of work in one minute; the value N is, then, taken as a certain number of turns per minute, commonly indicated by the letters R. P. M. in practice, so we have for the horse-power necessary to lift the weight W, with the device shown in fig. 30,

$$\text{H. P.} = \frac{2\pi WCN}{396000} \qquad (10)$$

in which

C = Drum radius.
π = 3.1416.
W = Load lifted.
N = *R. P. M.*

In practice the problem comes simply in the form of a certain number of H. P. to be transmitted, and a careful study of the above will make clear the manner in which the term horse-power involves all the elements of load, diameter of pulley or drum, and revolutions per minute; now the work required as found in formula

10 in horse-power terms must be carried by the shaft, and if we replace the load moment Wc in 10 with the resisting moment of a shaft $\frac{S_s I_p}{r_s}$ we have the horse-power which a shaft of given size will transmit, or knowing the H. P. we may determine the necessary diameter of shaft to transmit it, since the resisting moment of the shaft must be equal to or greater than the moment due to load; so we notice that the simple term "horse-power" (H. P.) on one side of the equation will involve all the features of load, diameter of pulley, and number of revolutions, for a given case, while, on the other side we have the necessary properties of the shaft and number of revolutions per minute as follows:

$$\text{H. P.} = \frac{2\pi N}{396000} \times \frac{S_s I_p}{r_s} \qquad (11)$$

to transmit a given horse-power. The proper meaning of each letter used in the above formula is:

H. P. = Horse-power to be transmitted or which a given size shaft will transmit.

π = 3.1416

N = R. P. M. at which shaft is to run.

S_s = Safe shearing strength of material in #□″.

I_p = Polar moment of inertia.

r_s = Radius of shaft in inches.

As an illustration of the application of this formula, we will determine the number of H. P. which can be transmitted by a 2″ shaft, running 100 R. P. M.

Numerical values are:

$\pi = 3.141$

$N = 100$

$S_s = 7000$ (Using factor of safety 10 for soft steel taken from Table 2.

$I_p = (1/2\pi r^4)$ (See Table 19.)

$1/2 \times 3.141 \times (1)^4$, or 1.57.

$r_s = 1$

Inserting numerical values we have

$$\text{H. P.} = \frac{2 \times 3.141 \times 100}{396000} \times \frac{7000 \times 1.57}{1} = 17$$

or such a shaft under the conditions mentioned will transmit seventeen horse-power. The formula may be used with equal ease in answering the question if put in the following form:

What size shaft, running 100 R. P. M., must be used to transmit 17 H. P. (Q. E. D.).

This formula gives a size of shaft available for transmitting power only, such as a countershaft; if main-line shafts or jack shafts are being designed, reduce the H. P. 50%, for example, if the above question called for a jack shaft we would say that it was available for a power transmission of 8.5 or 9 H. P.

Belting.—Belting is used in practically all work where shafting is introduced, hence it may be logically taken up in a brief way at this time; the belts commonly found in practice are made either of leather or rubber, and in ordering the specification should include the length, width and ply; thus in the case of leather belt, we may say, 40 ft. of single ply leather belt 6″ wide, if we wish what is known as a single belt, or we introduce the word double ply, other items the same as above, if we want the same amount of double belt; in placing leather belt on the pulley, the best results are ob-

tained if the smoother side is next the pulley surface; belting is a very broad subject, much discussion has been brought to bear on it, and many rules laid down; in practice many such rules cannot be applied, but at the same time certain limits must be observed, if reasonable satisfaction is expected, and the following notes are serviceable as a general guide: For main driving belts distance between shaft centers should not be much less than 20 ft., and for countershaft work, keep the shaft centers at least seven times the width of the belt apart; double belts should not be run on a pulley less than 12 or 14″ diameter, and triple is best limited to about 24″ as the smallest pulley, while quadruple (or four ply belts) should run on nothing smaller than 3 ft. Average practice for the surface speed, by which is meant the speed in feet per minute at which a point on the circumference of one of the pulleys travels, may be taken as about 3500 ft., though many belts are running at a much slower speed than this, while the greatest efficiency calls for a much higher speed. (See Kent's "Mech. Engs. Pocket-book on Belting.") For the calculation of amount of power which a belt may be expected to transmit, the following formulas are serviceable, taken from Kent's "M. E. Pocket-book":

For a single belt.

$$\frac{A_c}{180} \times \frac{WV}{733} = \text{H. P.} \qquad (12)$$

In which the letters have the following meanings:

A_c = Arc of contact in degrees.

W = Width of belt in inches.

V = Surface velocity of belt in feet per minute.

A double belt is usually assumed to transmit about 1 1/3 times as much power as a single belt, hence from this fact we may easily deduce a simple formula for such application by multiplying the above by 1 1/3 or 4/3, hence we may say, formula for horse-power of double belt is as follows:

$$\frac{A_c}{180} \times \frac{WV}{733} \times \frac{4}{3} = \text{H. P.}$$

the letters having the same application as in the previous case.

Arc of Contact.—As the power of a belt is effective due to the fact that a certain portion of it is in contact with the surface of a pulley, it is but reasonable to

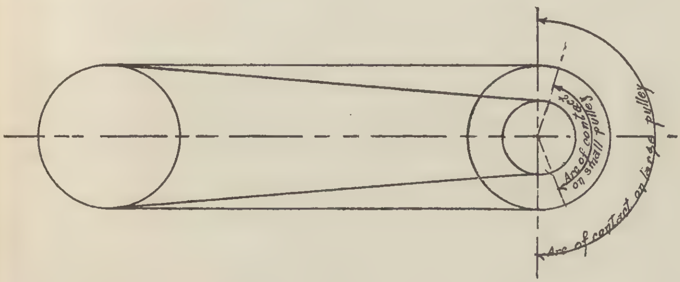


FIG. 29.

suppose that the portion of the pulley surface that is in contact with the belt will affect in a measure the amount of power transmitted, and this is in fact a truth; looking at fig. 29 we see two conditions represented, one in which the belt embraces about one-half the circumference of the pulley on both driver and driven, while in the other case more than half of circumference

covered on the driver, but less on the driven. In such a case the calculation of the belt power is always based on the smaller of the two pulleys with which the belt is in contact; the portion of the circumference on which the belt bears is known *as the arc of contact*, which is clearly indicated in the cases of fig. 29 by the arrow points; this value is commonly measured in degrees, and enters into our calculation of belt power as follows: If the arc of contact is 180° the H. P. transmitted will be the same as that evolved by the formulas given, if the first term is omitted since $A_c = 180$ and $\frac{180}{180} = 1$ but suppose we have an arc of contact of 90° then we will use the formulas as given above and take $\frac{90}{180}$ as the first term; this formula may be improved upon for surface speeds of over 3000 ft. per minute, by using methods contained in papers presented before the American Society of Mechanical Engineers by Messrs. Taylor and Barth.

To determine the arc of contact, the pulleys may be laid out to scale for diameter and center distance, and the arc of contact determined with a protractor if the shafting has not yet been installed; if the shafting is in place, a string may be stretched over the two pulleys, and the length in contact with the pulley cut out; measuring this section into the circumference will give us the portion of 180° which is embraced by the belt, or the arc of contact.

A single belt is about 1/4″ thick, double 5/16″, and triple 3/8″ thick when of leather, and most belts now

in use are of this material, though rubber belts are much used in places where there is considerable dampness; waterproof leather belting is being put on the market by manufacturers at the present time, and gives very satisfactory service; such material is sold under a special trade name, as a general rule.

Pulley Crowning.—If the face of a pulley, that is, the surface on which the belt runs, is perfectly flat, or the

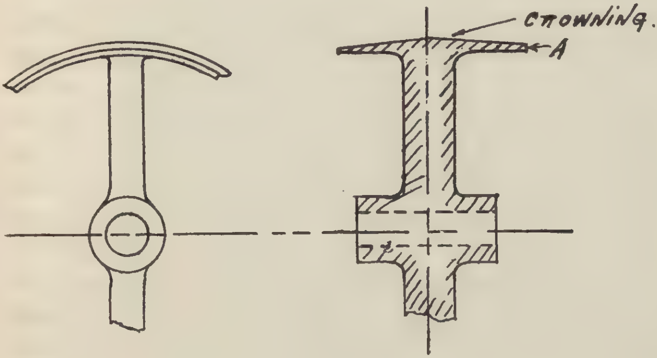


FIG. 30.

pulley is truly cylindrical in form, the belt will not remain in place but will run off the pulley when operating; to this end it is necessary to make the pulley larger at the center than at the edges, and such increase in diameter is known as "*crowning*" a pulley; different parties suggest various amounts of crowning, but average practice calls for an increase of about 3/8″ in diam. per foot of length each side of center, so that if we had a pulley of 6″ face there would be 3″ each side of center, and as this is 3/12 or 1/4 ft. the increase in diam.

from edge of rim A, fig. 30, to the center will be $1/4 \times \frac{3}{8}'' = \frac{3}{32}''$; in designing a drive this feature must not be overlooked if success is expected. Other features in connection with the belt drive are methods of lacing, splicing, calculation of speed ratios, all of which must be well understood by the man in charge of a plant; such subjects however belong to shop calculations and methods rather than in the class of materials with which this work deals.

It is necessary, however, to know how much pull a belt exerts on any elements which act as supports for driving or driven machines; the weight of the machine itself must always be considered in designing such supports, this weight being obtained from the builder supplying the equipment, or the designer must determine it himself; to this must be added the pull of the driving belt; if a given horse-power is to be transmitted, and the belt speed is known, it is a simple matter to determine the number of pounds pull due to such work; this pull is exerted by the driving or tight side of the belt, and there is also a load on the slack strand; it is evident that the support must carry both these loads; for average practice in such work one may assume the stresses equal in both strands, hence the load due to the drive, coming on the support, will be equal to twice the load, due to the transmitted H. P. Below will be found a problem illustrating the application of this principle.

The simple calculation of speed for pulleys and gears is based on the rules of proportion, such speed being inversely proportional to the diameters of pulleys or gears; to illustrate, suppose we have a pulley 36″ diam.

on a driving shaft, and it runs 200 R. P. M.; we wish to drive another shaft 500 R. P. M., what diameter pulley should be placed on the driven shaft? A direct proportion will be:

$$36 : X :: 200 : 500$$

and inverting one of the ratios we have:

$$36 : X :: 500 : 200 \text{ or } X = 14.4''$$

The method of using the formulas for horse-power of belting and determination of pull on a support is illustrated in the following:

A vertical belt is to be used for driving a machine, which requires 7.5 H. P. and runs 1500 ft. per minute; the complete countershaft weighs 300#. This is to be supported by four lag screws.

Select proper size single belt for this work, and give specifications as to size and boring of holes for lag screws. The arc of contact is 120°.

Formula 12, p. 92, should be used for belt, and introducing known numerical values from the problem we have:

$$\frac{120}{180} \times \frac{W \times 1500}{733} = 7.5 \text{ H. P. or } W = 3.5'' +$$

width of belt will be 3 1/2″. Relative to the pull on the lag screws we have: One H. P. = 33,000 ft.-lbs. per minute and 7.5 H. P. = 7.5 × 33,000 or 247,500 ft.-lbs. As the belt speed is 1500 ft. per minute the pull in pounds necessary is:

$$\frac{247500}{1500} = 165\#$$

In considering the stress on the supporting lag screws, however, this pull will be doubled, or we have 330# to

this we add 300#, weight of counter and we have as a total load 630#; using a factor of safety of 10 we will select screws to carry 6300#; since each screw will carry 1/4 the total load we must carry 1575# with each screw. If the wood into which screws were set was well seasoned, we might use a 3/8″ screw, but the wiser course would be to use a 1/2″ screw, bore with a 3/8″ bit, and

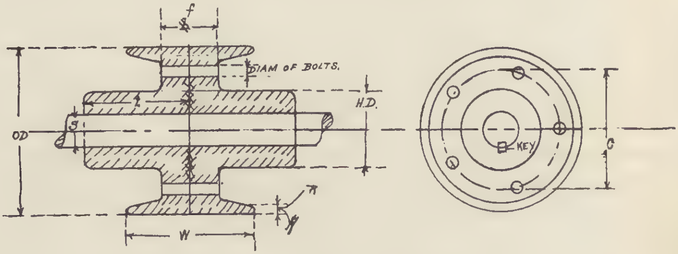


Fig. 31.

Flange Coupling Proportions.

S = Diam. of shaft.

H. D. = (Hub diam.) = 1.75 S + 1″

C = (Diam. of bolt circle) = 2.5 S + 2″

L = (Length of half coupling = 1.2 S + 1″)

Number of bolts used = .5 S + 3. (If fractional use nearest whole number.)

Diameter of bolts = $\frac{S}{\text{Number used}} + \frac{1}{4}''$

O. D. = (Outside diam.) = 1.4 C.

f = (Thickness of flanges) = .5 S + .6″

W = (Width of face) = 2f.

R = (Thickness of rim) = .12 S.

Key, make square and equal .25 diam. of shaft across flats, length = 2L.

set screw into wood 3 1/2″ as we see by looking at Table #21 B. If the surface speed of the belt had not have been given direct, it would have been necessary to find it from the diameters and number of revolutions per minute of the pulley.

Shaft Couplings.—In dealing with shafting, belting, etc., one is often called upon to design a connection for long lengths of shafting at the end; many patent couplings are available through mill supply houses, but the

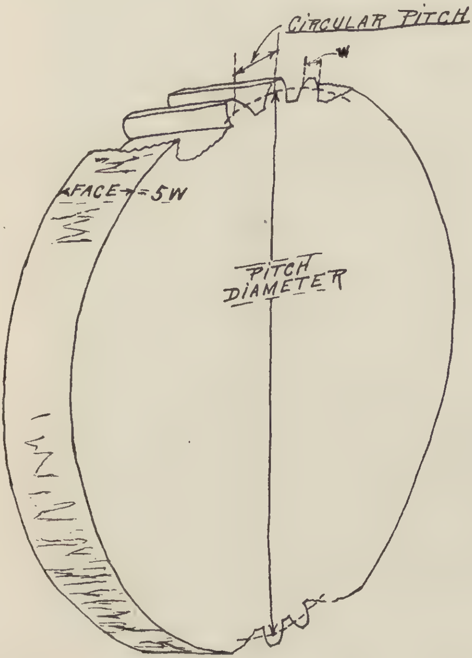


FIG. 32.

one known as a flange coupling, shown in fig. 31, when properly designed, is safe, efficient, and a good design; in the solution of problems given in connection with this chapter, it may be satisfactorily applied; the

proportions of various parts are given directly on the figure.

Strength of Gear Teeth.—A gear tooth is a cantilever and in calculating its strength it will be well to look over p. 66, that the steps may be properly covered. A few gearing terms must be understood, if we wish to make practical use of this study, though the shop

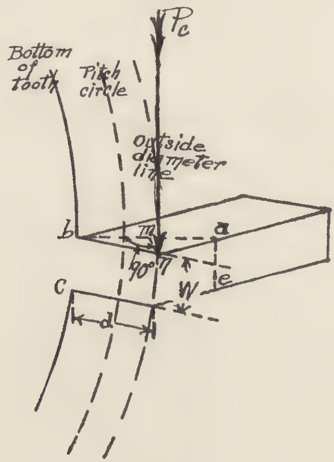


FIG. 33.

technic will be left for the work devoted to that subject. Fig. 32 presents such terms as are essential to the application of the process of design presented; here we see that the thickness of the whole gear at the section where the teeth are cut is known as the face; that the diameter of a circle, the extremities of which lay at mid-points of tooth depth is known as the *pitch* diameter; the distance from the center of one tooth to

the center of the next is known as the circular pitch and the width of the tooth W at the pitch line equals one-half the circular pitch. This value W is the one which we desire to determine, and knowing this, we may apply the specific rules of gearing, to determine any necessary data for use when making the gear in the shop. The pitch diameter will be introduced when we make calculations of speed, for determining number of pounds load due to a given horse-power transmitted, the same as was done in determining the pull coming on one strand of a belt (see p. 97). The weight in pounds thus obtained is treated as a load P_c, fig. 33, coming on one corner of the tooth and the section *abce* is treated as that of a rectangular beam, the length of which is *mn*, and height of which is W. The distance *ab* of course is the breadth b of the beam. The relation of these values to W are as follows:

$$\begin{aligned} b &= \text{breadth of beam} = 1.93\, W \\ l &= \text{length of beam} \;\; = \;\; .96\, W \\ h &= \text{height of beam} \;\; = W \end{aligned}$$

On p. 59 we have given the relation existing between resisting moment and maximum bending moment, and if we work through the formula we shall find that

$$\overset{\substack{M_r \\ \downarrow}}{1.93W^2S_u} = \overset{\substack{M_B \\ \downarrow}}{5.76P_c} \tag{13}$$

from which we may determine W or the width of tooth on the pitch line.

If the problem comes in the form of moving a given weight at a certain speed, the work of determining the load coming on a tooth is simplified, as an application of the principle of moment will give the tooth load

directly. To illustrate the application of the formula we may solve the following problem: A gear transmits 5 H. P. The velocity in feet per minute at the pitch line is 100; what should be the width of the tooth at pitch line? 5 H. P. $=5\times 33{,}000=165{,}000$ ft.-lbs. per minute; as the velocity in feet per minute is 100 the load in pounds must be 1650, which is thrown on the tooth; introducing numerical values in formula (13), using a factor of safety of 4, we have

$$S_u = 7500$$
$$P_c = 1650$$

(See Tables 2 and 4)
hence

$$1.93W^2 \times 7500 = 5.76 \times 1650$$
$$W^2 = .65 \text{ or } W = .81''$$

which will have to be changed to some extent to meet shop requirements.

The value of S_u in this illustrative example was taken from a common table, as used for beams, but unless the speeds are low it is best to use the values of S_u given especially for gearing in Table 2A, which are adapted from Kent's "M. E. Pocket-book."

As noted in fig. 34, the width of face of a gear is $5W$. Such a proportion is good practice though it may often be departed from to a greater or less degree.

Stresses and Calculations of Same in Small Tool Design.—The application of strength of materials in the design of small tools, such as jigs and fixtures, involves calculations for columns and beams, in the same manner as already studied; in cases of determining loads thrown on such tools due to cutting,

one must often adopt a comparative method of determining the stresses, as will be noticed in calculations following in this section; small tools as referred to means cranes, trucks, jigs, and similar equipment; while there is much to jig design beside the simple calculation of stresses, the stress feature is the only one coming within the scope of this work.

Fig. 13 shows several sections much used in this class of design, but stress calculations are made on the base form, not including the fillet *f* or ribs *r* which are introduced by the designer to prevent cracks and the rapid wearing out of clamp faces; malleable iron is often used as clamps, and sometimes cast iron; steel is by far the more common though, and the section commonly used for clamps is rectangular. In applying sections similar to those in fig. 13, *A* is treated as a T-form, *B* and *C* as simple channels, while *D* and *E* are of rectangular and square section; the formulas of Table 8 may be used in determining the numerical values of properties of these sections. As an illustration of the method available in determining stresses by comparison of conditions in separate elements we may study the case of a jig which is in service on a multi-spindle driller, to be used in drilling four 1″ holes at one time; the jig is to set on four feet; what would you make the combined area of these feet, that they may be safe against crushing under the greatest load that might be applied. The assumption is first made that the downward pressure would be so great that the drills might be twisted off, and feet designed to sustain this load, drills being taken in section equal to that of a 1″ tool steel bar.

Referring to pages 87 and 88, etc., the formulas are given as:

WC the load moment and

$\frac{S_s I_p}{r_s}$ for resisting moment

in dealing with a round bar.

Numerical values are

$W =$ The load that will twist the drill off.
$C =$ Rad. of drill 1/2″ or .5″.
$S =$ 90000#. See Table 2.
$I_p = \frac{\pi r^4}{2}$. See Table 18.

The calculation then is

$$.5W = \frac{90000 \times 3.1 \times 1/32}{2} \quad W = 93,000\#$$

approximately, to twist off one drill or 372,000# necessary to twist off four drills; this is the load at the circumference which would twist off a solid 1″ bar, multiplied by four; assuming that it requires the same pressure in all directions to force a cutter into metal, we say that this tangential force which we have just calculated is equal to the force required to "feed" or constantly push these four drills through the stock, and we have a load of 370,000# coming on the feet of the jig. Using this as a dead load, since the drill starts gradually and "feeds" steadily we must use a factor of safety of four, and a stress in the feet of 22,500#□″ hence total area must be $\frac{372000}{22500}$ or about 16 sq. ins., and with four feet, each foot should have an area of four sq. ins.

The same process of reasoning may be applied to

stops, supports, etc. In the case of milling fixtures the stress is that necessary to twist off the arbor used to drive the cutter, or in a lathe driving fixture that load necessary to break the tool of largest size which may be used in the post; as will be seen from the above illustration, no variation of the methods for simple calculation in compression, shear, beam design, or column work, are introduced, the only feature requiring special consideration being the determination of the load coming on the fixture; in some of the larger plants where many jigs are made, the load as determined above is decided by test, and values tabulated, in which case the assumptions presented are unnecessary.

PROBLEMS.

1. Fig. 34 is a diagrammatic sketch of a small power hoist. Select the proper size shaft for the main gear as indicated at B and the proper width at pitch line of a gray iron gear tooth to carry the load assuming that a 5 H.P. motor is exerting full H. P., what should be width of face of gear and pinion? *Ans.* *1 1/2″ shaft . . . .25″ . . . 1 1/4″* *See Table 2A for values of* S_u.

2. A shop for experimental work is to be equipped with the following tools: One shaper, one 10″ lathe, one universal milling machine, a band saw, and a surfacer. All these tools are to be driven from one line shaft, by means of a motor, bolted to the ceiling, how many H. P. must motor be, assuming that all machines will be running at the same time, what size belt for a main driving belt, what size shaft for a main shaft, and what size bolts to hold motor to ceiling, assuming belt pull horizontal, and four bolts to be used. (See Tables 21A and 22.) Motor is to run 900

R. P. M. and line shaft to run 175 R. P. M. State proper diameters of pulley on motor and line shaft, center distance of shafts to be 8 ft.

3. Suppose the above motor were suspended from the ceiling as mentioned, but due to placing the line shaft against the wall below the motor, the pull on belt became vertical, what size bolts should be used for suspending same?

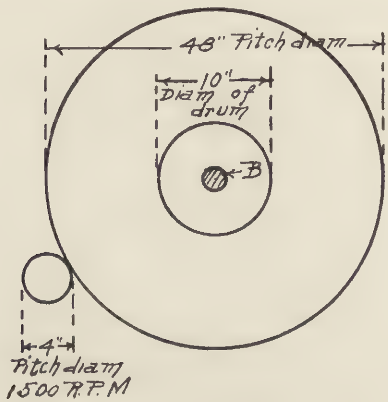


Fig. 34.

4. A hand winch is to be designed for shop use, similar in arrangement to that in fig. 34, except that the main gear is to be 48″ P. D. and the small gear, to which a handle is attached instead of a motor, is to be 6″ diam. a load of half a ton is to be lifted by means of a rope running from the drum; select shaft through main gear and drum, also state thickness at pitch line of gear tooth, and width of gear face.

5. A testing frame used in the laboratory of an engineering works is supported by means of four angle irons which are eight ft. long. This frame carries a 15 H. P. motor run-

ning 1000 R. P. M. geared to two countershafts, one of which runs 200 R. P. M. and the other 75 R. P. M. Assuming that at different times, the whole power of the motor may be transmitted through either counter, what diameter gears must be used for desired speed, size of tooth (pitch line width, and face) and what size shafts on the counters?

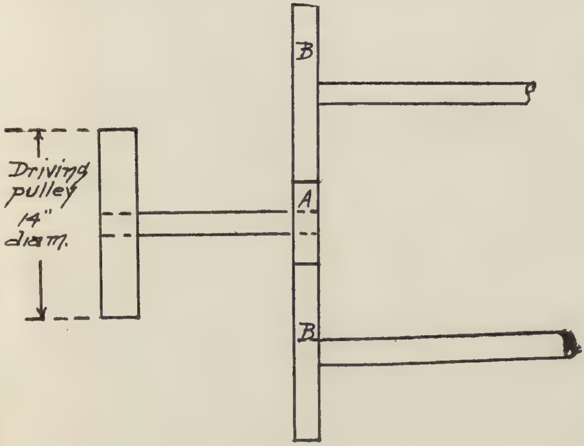


FIG. 35.

6. The main driving shaft for a shop runs 200 R. P. M. and transmits 100 H. P. What size belt would you select, assuming a belt speed is 2500 ft. per min.? What size shaft to transmit this H. P.?

7. Give your specifications as to tooth width at pitch line and face for a steel pinion to transmit 25 H. P. if it is 8″ P. D. and runs 750 R. P. M.

8. Fig. 35 shows a diagrammatic arrangement of a boring fixture; the pulley carries a 2 1/2″ belt running at rate of 1500 ft. per minute, 180° arc of contact. The gear A is 4″ P. D. and other two are each 8″ P. D. Give the speci-

fications for thickness and face of tooth, assuming belt is exerting full power, according to formulas given in this book.

9. In designing the clamping system for a jig it is decided to use as clamps, stock of ribbed channel section as shown at C fig. 35, malleable iron, the clamps are set up by means

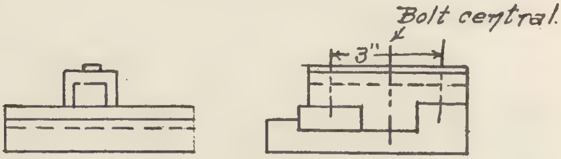


FIG. 36.

of 5/8″ bolts, if we desire the clamp to be sufficiently strong to stress the bolt, which is of soft steel, to the elastic, limit what size should the clamp be of malleable iron; fig. 36 shows the arrangement of clamp in jig.

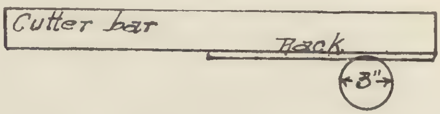


FIG. 37.

10. A driving shaft must transmit 75 H. P.; it is equipped with a pulley 20″ diam. and runs 200 R. P. M., from this I wish to run another shaft at 135 R. P. M. Select size of shaft for driver, size of belt and diameter of pulley for operating driven shaft.

11. An engine running 225 R. P. M. develops 8 H. P. It has on the driving shaft a pulley 8″ diameter, which connects to a shaft running 80 R. P. M. If the shaft must carry the

horse power mentioned above, and belt pull is vertical, determine following:
Diam. of pulley on shaft;
Diam. of shaft;
Pull due to belt.

12. In the design of a broaching attachment, a load of -250# is thrown on the cutter bar which is driven by means of a rack and pinion as shown in fig. 37. What must be

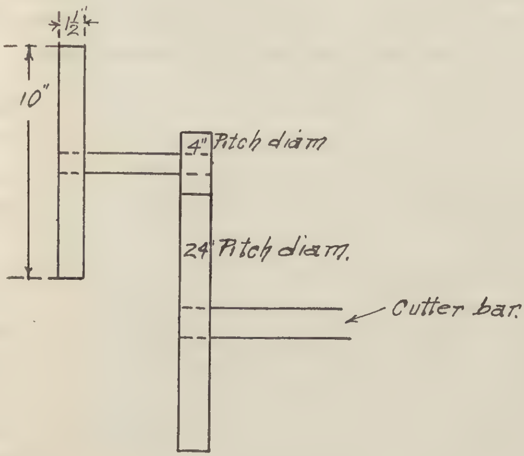


FIG. 38.

pitch line thickness of tooth and face if pinion makes 20 R. P. M., the pinion and rack teeth being made of hard steel?

14. Fig. 38 shows the gearing arrangement for a special facing fixture; it is driven by a 1 1/2″ single belt, and the pulley shown runs 75 R. P. M. Give specifications for thickness of tooth and width of gear face if the gears shown must carry the load due to the H. P. which the belt mentioned will carry.

CHAPTER VII.

THE ACTION OF ELEMENTARY FORCES AND THEIR CONSIDERATION IN DESIGN; PROPORTIONS OF KNEES AND COUNTERS.

When a piece of construction is so put up that all forces act in the line of the members, such forces are taken as producing a direct stress, that is, in the piece of construction, fig. 1, the load from beam on the column is carried by the end of the column and the forces acting that sustain the beam (reactions) are in line with the center of column as indicated by the arrows *e*. If we determine the amount of load coming at the beam end, then in this case we have all that is necessary, so far as the load is concerned, to select the size of the column; we do not have so simple a problem in all cases, however, as is illustrated in the design, fig. 39, which shows a wall crane much used in factories; in making the calculations on such a job, we determine stresses in the tie, and I-beam, as well as considering the stress in the wall in order that the crane may be properly supported.

B represents a load at the end of the arm; if we wish to know the stresses created by the load it will be necessary to apply the **triangle of forces**; this combination is much used in determining stresses. Assume

that the load B is represented by a straight line; it makes no difference what its length is, as it is not measured, in the method to be used; this line ab fig. 40, indicates the direction of the load; the angle x fig. 39, is known from the requirements of the job; we will draw a line ac and bc; the first of these is

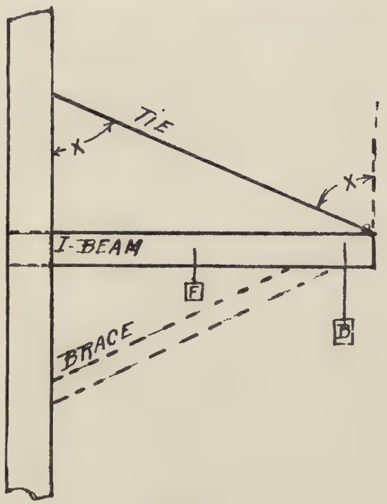


FIG. 39.

assumed to make the same angle with the load line in fig. 40 as the tie does in fig. 39, while bc is parallel to the line of the beam; applying trigonometry we have

$$\frac{ab}{ac} = \cos x \text{ or } \frac{ab}{\cos x} = ac$$

if now we make ab equal to the load in units, we can easily determine the stress in ac; also

$$\frac{bc}{ab} = \tan x \text{ or } bc = ab \tan x$$

so knowing the load, we have been able to determine the stresses in the two other elements of our piece of construction. We see then, that the fact of a supporting element being out of line with the load makes a marked difference in the stress.

In determining the nature of the stresses in these elements, that is, whether they be tension or compression, place an arrow indicating the direction of load *ab* which is downward in this case, and from this point the arrows must continue in order around the figure until

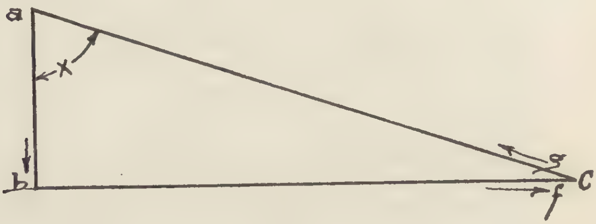


Fig. 40.

we reach the starting point *a* again. If the arrow on the diagram, representing the stress in any member, points toward the joint with another member, as arrow *f*, representing stress in the I-beam, points toward *C* it indicates that the member (I-beam in this case) is in compression; if the arrow points away from the joint, as arrow *g*, representing stress in tie, points away from joint *C*, it indicates that the member (tie in this case) is in tension; the design we are studying must have an I-beam acting as a column, a tie rod, and

the wall of sufficient strength to take the thrust of I-beam and pull of tie safely.

The load *B* may not be located at the extreme end

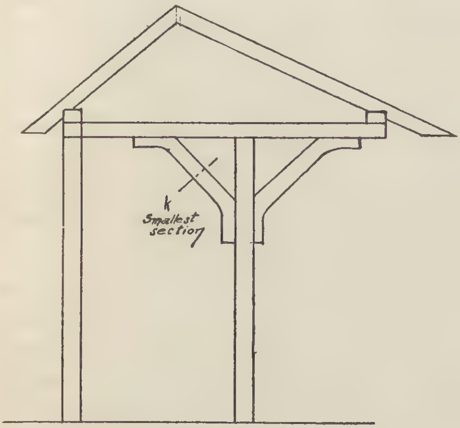


FIG. 41.

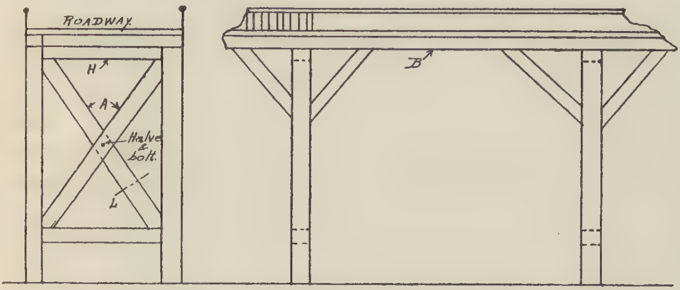


FIG. 42.

of the beam, but is moved to a point anywhere along its length in the case of a crane; the I-beam not only acts as a column under such conditions, but as a beam

also. The tie then simply acts as a support at one end of beam, and after determining reactions it may be selected; the load is assumed to be at the ends in the case of a crane when designing the supports, because in this position it carries the greatest stress to supports, while for bending moments it is taken in such a position that the greatest moment is produced.

The course of reasoning outlined above holds in all applications of the triangle to constructive work, it makes no difference whether the beam be supported through the medium of a tie, or by means of a brace as indicated by the dotted lines in fig. 39.

Counterbracing is used for the purpose of giving rigidity to structures; figs. 41 and 42 show two forms, that at 41 being known as knee bracing; the design represents the section of a type of shelter shed used in parks, playgrounds and at railway sidings; the other design is used in building elevated walks or driveways; the proportions of these members are usually related to other members of the construction for which calculation has been made in the design, rather than by calculation of stress in the braces themselves. The sectional area at the smallest part being made from *half to full size* of sectional area of the post or column; if the counters are long, about equal to length of posts as in fig 42 at A, the sectional area at any place *L*, would be made equal to the post, being "halved" at the mid length and bolted together; these members are usually spiked in place; the beam *B* in fig. 42 is designed on the basis of the load it must carry, while the header *H* is made the same size as beam *B*. If

such a design is put up in steel, the beams and columns would be I-beams, and the counters channel beams.

The action of the weight of a machine, resting on several feet, or a flanged base must be considered in the design of a structure to support it, as either a series of concentrated loads, or a uniform load; if the feet on which the machine rests are not more than one foot apart, the weight is assumed to be a uniform load, the

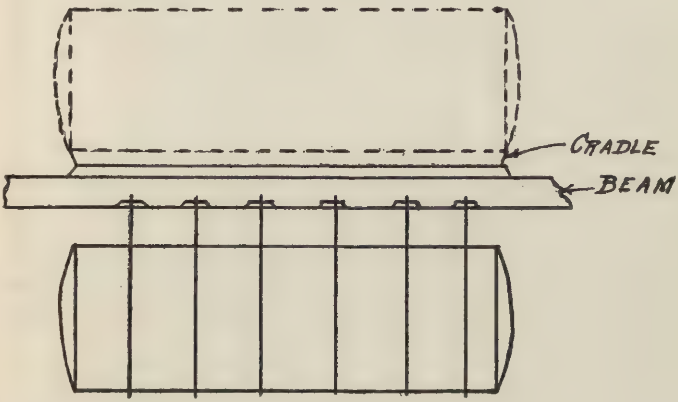


FIG. 43.

same as though it rested on a rib; such a case is illustrated in fig. 43, where a water tank is shown hanging from a beam by means of slings, and also setting in a cradle, on top of the beam; both methods of support would be considered as producing a uniform load, in making calculations to determine the proper size beam to be used. If the supporting elements (feet or slings) are more than a foot apart, they are taken as points of application of concentrated loads, and the amount of

such load on each sling will be the total weight to be supported, divided by the number of feet or slings; thus if we have a tank which with its supply of water weighs 2000# and we have four slings, then each sling carries 500#. In the case of a machine we must look carefully into the distribution of the weight, that we may be sure it is evenly placed; usually this is the case, however, and even when such is not *strictly* true, the designer of a supporting structure does not attempt to find out the variation, but assumes even distribution and proceeds with his design, depending on the F. S. to cover all necessary requirements.

The beginner should be careful, when working out a design, that he does not entirely neglect the effect of feet, or pads on a machine, in concentrating the loads on a structure; one very common error being the assumption that the whole weight of the machine is carried on one or two feet, due to a neglect in studying the construction of that part of the machine which rests on the floor or platform.

Illustrative Problem in Beam Design Using Steel Construction and Bracing with Knees.

Problem.—A small blowing unit is carried on cantilevers as shown in fig. 44. Select proper steel for both cantilevers and knees and state amount of thrust coming on the wall.

Looking carefully at the drawing we see that the machine sets on four pads, two resting on each beam; such being the case one-fourth of the total weight will come on each foot or a load of 112#, which for convenience we may call 115#; such loads fall respectively

12″ and 36″ from the wall center; as these beams are to be supported by a knee at the outer end we will deal with them as simple beams, supported at both ends, and since we have two beams, one-half the total load will be distributed by means of two concentrated loads on each beam, hence a design for one beam will be suffi-

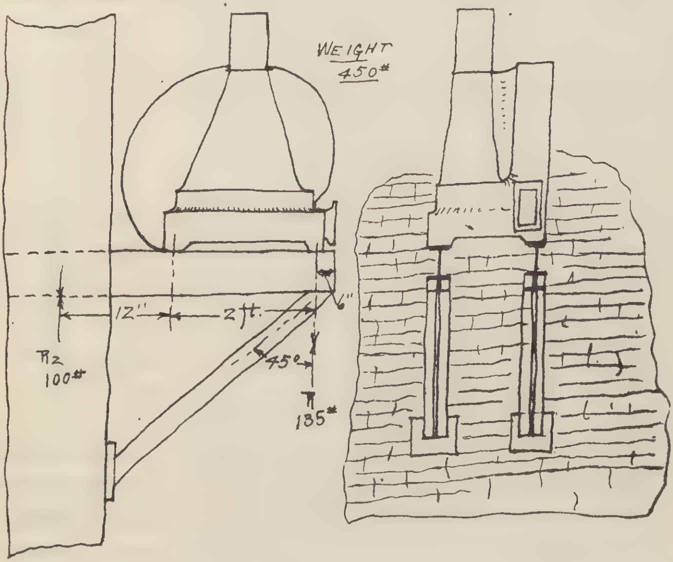


FIG. 44.

cient, using the same design a second time for the other beam.

Reaction R_1 will be taken by the knee, while R_2 will be taken by the wall; applying the solutions already presented we have:

$$42R_1 = (36 \times 115) + (12 \times 115)$$

R_1 assumed to act at extreme end of beam

$$R_1 = 131 + \text{ call this } 135$$

and

$$42R_2 = (115 \times 30) + (115 \times 6)$$

or

$$R_2 = 99 \text{ call this } 100$$

The sum of actual loads is 224# but due to the slight changes made for convenient calculation we deal with 235#.

The next step, finding the maximum bending moment, and working out we have:

$$M_b = 100 \times 12 = 1200$$

$$M_b = (100 \times 36) - (115 \times 24) = 840$$

By inspection of these values we see that M_B lies under the load nearest the wall and is 1200#″.

We know (see p. 48 and resumé of notations) that $M_r = S_u \frac{I}{c_n}$ and hence to be safe

$$S_u \frac{I}{C_n} = 1200\#'' \text{ must hold true.}$$

Looking at Table No. 4 dealing with factors of safety we will use twelve as a factor of safety, because such equipment is apt to produce shocks. The material we are using is weaker in tension, being about 50,000# per sq. in.; see Table 2, and using a factor of twelve we may use for $S_u = \frac{50000}{12} = 4166\#$, which we will call 4100#; substituting values we have:

$$4100 \times \frac{I}{c_n} = 1200 \text{ or } \frac{I}{c_n} = \frac{4100}{1200} = 3.41$$

the section modulus.

Looking at Table 8 we see that a 4″ heavy I-beam has a sec. mod. of 3.6, hence we will use this for the main beam.

As to stress in the knee we have, applying the triangle of forces:

$$\frac{135}{x}=\cos 45^\circ$$

or

$$\frac{135}{\cos 45^\circ}=x=\text{stress in knee.}$$

Looking at a table of co-sines we find $\cos 45^\circ=.707$, hence

$\frac{135}{.707}=x=191\#$ which we will call 200#.

This knee is really a column and could be designed as such, but this is not a common practice on small jobs, it being taken as mentioned on p. 114. An angle would be used for such a brace, and looking at Table 10 we see that a $3\times3\times1/2''$ angle will give a sectional area of about 3/4 that of the beam, and such a proportion would be a wise selection because the load will cause shock. Two angles would give a neater design, hence we may use $2\ 1/2\times2\ 1/2\times3/8''$ angles, placed one each side of the I-beam web. As to thrust on the wall if we apply the triangle of forces to the stress in the knee, we will find it to be 135#, which should be taken by an iron plate of sufficient area to insure remaining inside the unit shearing strength of brickwork (see Table 5) and attached to both the plate and I-beam by a riveted joint designed along ines presented in the chapter on riveted joints. For

method of holding an iron plate to brick or masonry, see Kidder's Architects Pocket Book under the heading of expansion bolts.

The Weight of the Members in a Structure.—A feature to be remembered in any extensive design or framework, is the weight of the various parts of the structure itself. In designing small structures there is no necessity for such consideration as a rule, but if the work is extensive this factor should not be neglected. The method of introduction is to add the weight of the beam or column to the actual applied load; let us assume that we are to design a steel beam to carry a uniform load of 150# per ft. 10 ft. long. Formula is

$$S_u \frac{I}{c_n} = \frac{1}{8} P_t l;$$

Use factor of safety of 3 we may make $S_u = 16000\# +$ and inserting numerical values we have:

$$16000 \frac{I}{c_n} = \frac{1}{8} \times 1500 \times 120$$

or

$$16000 \frac{I}{c_n} = 22500 \qquad \frac{I}{c_n} = 1.4$$

from which we select a 3″ light I-beam. The weight of this beam is 5.5# per ft. hence considering the weight of beam we will have for weight per ft. 155.5# which we will use as 156# and hence $P_t = 1560\#$. Introducing numerical values we have:

$$16000 \frac{I}{c_n} = \frac{1}{8} \times 1560 \times 120 = 1.46$$

and we find that a 3″ I-beam is still safe.

If the beam carries one or more concentrated loads,

instead of being uniformly loaded, its weight may be treated as a concentrated load, applied at the center of its span.

Distribution of Load on Floor Joists.—In the distribution of loads on floor joists, it is not a certainty

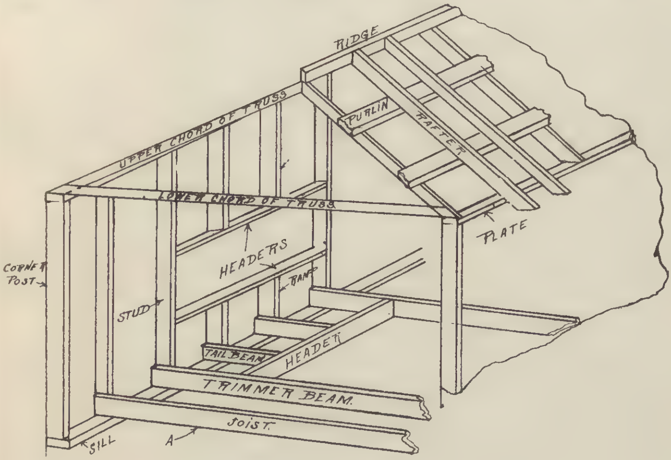


FIG. 45.

just what load will come on the whole floor; for this reason it is customary to design floors for certain purposes to carry a definite load and table #19, A, gives values used to a considerable extent as an average guide, though of course any building may be designed for a specific floor load varying from this.

A floor is constructed as shown in fig. 45, with joists resting on sills and the load assumed as coming on any joist is that laying between two successive joists; to illustrate: We have in the figure a floor which we will

assume to be 15 ft. wide, and the distance between joist centers 15″ or 1 1/4 ft. The joist *A* then will carry the load which falls on

$$15 \times \frac{5}{4} = \frac{75}{4} = 18\frac{3}{4} \text{ sq. ft. of area}$$

and if we are designing a shop store room this joist must support:

$$18.75 \times 120 = 2250\#$$

as a uniformly distributed load, all floor joists being the same size. The student should make a careful study of fig. 45 that he may know the parts of a common framework when they are mentioned.

Lag Screws.—Lag screws are much used in shops and buildings; Table 21, B, gives the loads necessary to pull out certain sizes; factors of safety must not be forgotten when using these values.

Rope.—Table #20, will be of assistance when selecting rope for any given loading, the approximate diameters given serving as a guide in selecting blocks. Rope is specified by "girth" or circumference rather than diameter however, and if you planned to use a rope about 7/8″ diameter it would be ordered as so many feet of hemp or cotton, or manilla rope 2 3/4″ girth.

CHAPTER VIII.

RIVETED JOINTS.

Study Table 16 carefully in connection with this chapter.

The purpose of this section is to cover riveted joints as applied in the construction of tanks used as oil or water storage and air receivers of low pressure; we will then become acquainted with the riveted joint, method of its construction, and the relation of its various elements one to the other.

A riveted joint may fail in one of several ways, or by a combination of these ways:

FIG. 46,

The plate may pull apart along the line of the joint as indicated at *A*, fig. 40

or

by crushing the metal of the plate and rivet as at *B* of the same figure

or

by splitting out the sheet as at *C* of the same figure

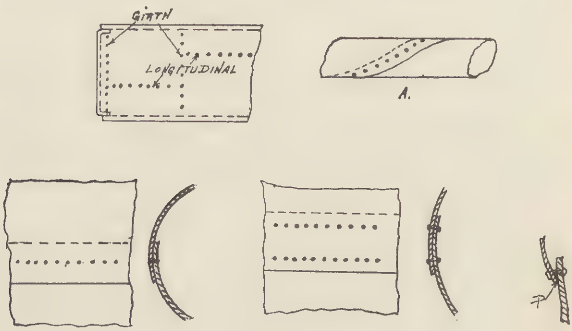
or

by simply shearing off the rivet as at 46 *D*

and again

in failing the rivet may shear, plate crush and pull apart and possibly split slightly, in which case we have failure due to the several weaknesses combined.

Before taking up the details of joint design we must consider briefly the construction of a tank in order that we may be familiar with the position of the various



B C D

FIG. 47.

riveted joints; looking at fig. 47, we see one joint running parallel with the axis of the tank, while others are made up around the circumference; those running parallel with the axis are known as the *longitudinal seams*, while those around the tank are technically termed "*girth*" or "*ring*" seams, and such joints are put up in all the types available, dependent on the requirements of the design; at *A* in the same figure we see what is known as the spiral joint, which has become common in pipe work during recent years.

Joint Classification.—Joints are broadly divided into two classes, *single riveted* and *double riveted;* a single riveted joint is understood to have but one row of rivets, while a double riveted has two rows of rivets holding the plates in place; single and double riveted joints are shown at *B*, fig. 47 (single riveted), and *C* (double riveted). Under each of these general types of joints we have the lap joint, butt joint with single cover plate and butt joint with double cover plate; at fig. 47, *B*, we see the single riveted lap joint and at *C* a double riveted joint of the same type. The lap joint has an important undesirable feature in that when it

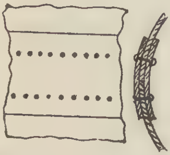


FIG. 49.

FIG. 50.

fails there is a tendency not only to cut the rivet off, but to bend it and the plate as well, as illustrated in fig. 47, *D*, where we see the rivet pulled and distorted, while the plate is bent about point *P*. To overcome such action, the butt joint in its two types, one with a single and the other with a double cover plate was devised; no figure is shown of the joint with a single cover plate, such an arrangement giving the same construction as in fig. 49, except that one plate, the *outside* one is used, and the inside one omitted; a study of fig. 49 brings out the fact that the bending action of both

plate and rivet are largely eliminated, placing the rivet directly in double shear; in this figure we have what is technically known as a single riveted butt joint with two cover plates, while in fig. 50 there is presented a double riveted butt joint with two cover plates; there are a great many other arrangements of joints possible, to meet varied conditions, but those presented are the fundamental types; for the average run of tank work the lap joint in some of its forms is satisfactory,

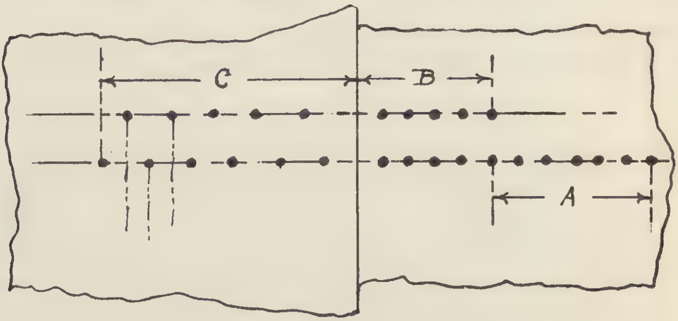


FIG. 51.

unless pressures approach 75 pounds or more, when the butt joint with double cover plates may well be considered.

Arrangement of Rivets.—In making up riveted joints the rivets may be placed in a row the proper distance apart, and relative to the edge of the plate both in the case of lap and butt joints; such placing is known as CHAIN riveting and is shown at *A*, fig. 51 (single chain) and at *B* (double chain), as applied to a lap joint; same specifications as above hold true for the butt joint as

to rivet arrangement. At C of the same figure we see what is known as *staggered riveting*, where, instead of the second row rivet standing directly back of that in the first row, as at B, it is set diagonally, half way between the rivets of the first row. Girth seams are commonly put up single riveted.

Joint Efficiency.—The efficiency of the joint is a very important element in the process of design, since it tells us directly the relation of the strength of the joint to that of the solid plate which we must use in our construction; *e.g.*, if a piece of the solid plate from which we build a tank sustains an ultimate stress of 20,000# and we take a joint involving a piece of the same size as that tested and find it will carry a load of but 10,000# before breaking at the joint, then the joint is but half as strong as the plate, or its efficiency is 50%. Reasoning from the above simple calculation, we may deduce a definition for joint efficiency as follows:

The efficiency of a riveted joint is the ratio of the strength of the joint to strength of the solid plate.

Numerical Values of Joint Efficiencies.—In testing the efficiency of two samples of the same joint they will vary to some extent; again, different authorities give unlike values for this item, so that the best one can do is to select an average as a guide, and such is the purpose of presenting the following in this connection:

Single riveted lap joint, 55%.
Single riveted butt joint, with single cover plate, 55%.
Double riveted lap joint, 65%.
Double riveted butt joint, two cover plates, 70%.

The single riveted butt joint with one cover plate is

not recommended for practice, since it adds to expense, without great increase of efficiency over a lap joint, while the double riveted butt shown adds but a comparatively small amount in cost over the single riveted butt, and gives a marked increase in efficiency over any other type of joint.

Design of Joints.—The design of joints for tank and receiver work must take up the consideration of other features than the ultimate breaking of the joint, since it is entirely possible to so construct a joint that it will not actually fail, but still not hold a fluid substance without leaking. The efficiency values just presented will assist us in selecting the type of joint for any given case, and known pressures will enable us to select the proper thickness of plate; on this selection of plate the other elements of the joint are based, working along well defined lines, as to size of hole in plate, size of rivet, and features of spacing.

Rivet Sizes.—Certain sizes of rivets are considered satisfactory for the various thicknesses of plates, and designers use a table of plate and rivet sizes in selecting to meet the requirements for any given problem; the holes are made somewhat larger than the rivet is, so that the rivet may be easily and quickly placed when it is hot, while the process of heading up is assumed to fill the hole as well as form the rivet head; Table No. 22, which is taken from Hutton's Mechanical Engineering of Power Plants, serves as a guide in this work.

Pitch of Rivets.—The pitch of a rivet is the distance from the center of one rivet to the center of the next measured parallel with the seam; this feature must be considered in designing, and like other factors, there

is considerable variation in practice, hence following proportions are presented as a guide, from which one may find a wide departure at times. The pitch is usually related to the diameter of the rivet, which in turn is related to the thickness of plate. **For single rivet lap joint and butt joint with single cover plate we may take the pitch as 2 1/4 times the diameter of the rivet.**

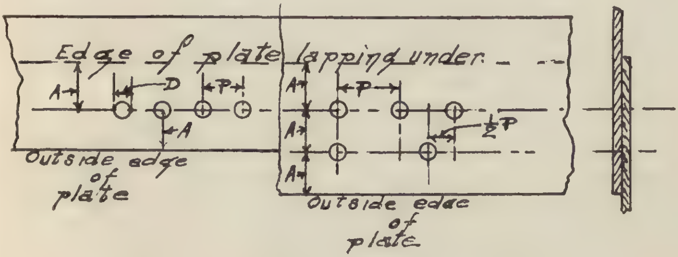


FIG. 52.—D = Diam. of rivet. A = 1 1/2 D.

For a double riveted lap joint use

3 3/4 times the diameter of the rivet.

For double riveted butt joints with two cover plates use

4 times the diameter of the rivet.

The distances between the two lines of rivets as well as the distance a rivet must be set from the edge of the plate are shown in fig. 52.

Solution of Problem Illustrating Application of Text to Riveted Joints. Prob. #14 of Following Series.

(See fig. 53.)

Since this is low pressure work, nothing but single riveted lap joints will be necessary; as the barrel is

but 4 ft. long, no girth seams are necessary, as I can purchase a plate 4 ft. wide and simply roll it up. My first step is to select size of rivet; as the steel is 5/16″ thick I see by Table 12 that I must use a rivet 11/16″ diam. and the holes must be 3/4″ diameter, and according to text on p. 129 they should be spaced 1 1/2″ apart; again looking at fig. 52 to guide me I find that the rivets must be set 1″ from edge of plate. As to method of holding bottom in place, assuming that I have no means of flanging, I will use an angle, bending it to the required shape; the pressure on such a part is

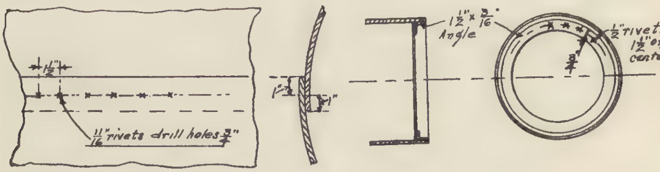


FIG. 53.

not easily determined, and judgment is relied upon to guide one; these heads must support a shaft, however, so I want a reasonably strong joint; I will make the ring half the thickness of the shell, which calls for 5/32″; the nearest thickness of angle listed is 3/16″, and following the Table No. 12 as a guide, I will use 1/2″ diam. rivets spaced 1 1/2″ apart; as distance from center of rivet to edge of steel angle must be at least 3/4″ (see fig. 52) I must use 1 1/2″ angle, and the rivet holes will be 9/16″. Select rivets and spacing of same for inside angles by applying rules and proportions given above, as illustrated in connection with the angle used for holding bottom in place.

PROBLEMS.

Note.—All tank work given is low pressure, that is less, than 75# □″.

1. Fig. 54 shows the rough sketch of a shelter shed to be built, the load assumed on the roof is 40# □ ft. Select size of rafters, if spaced 24″ apart, size of plate P, posts A, B, C, and braces D. (Load is assumed vertical on roof; its perpendicular component is not considered.) Sketch your own design of the various joints as you would have them made.

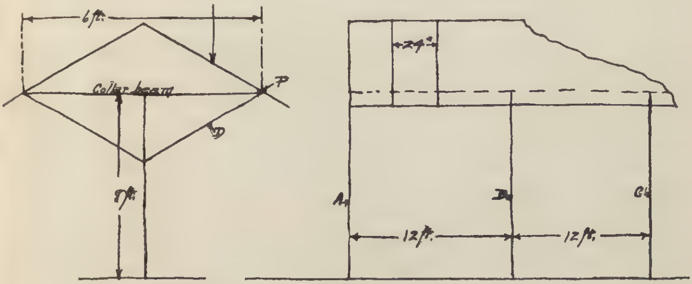


FIG. 54.

2. A motor which develops 15 H. P. running at 1200 R. P. M. having a 6″ pulley is to be carried on a timber framework 8 ft. high; the machine weighs 1500#; if framework must have four timber posts, and be braced with counters, get out full design, giving size of timbers; state the pull tending to tip the stand over, assuming belt runs horizontally.

3. Fig. 55 shows the arrangement for a tank support; this tank will be filled with water; design the main header A, columns B, small header C and counters at D, all in timber.

4. Fig. 56 shows the essential parts of a tank support, built into the wall; beam *A* is to be a steel I-beam and braces *B* are to be steel angles; select the proper size of each to carry the load and also area of foot plate *C*, so that sufficient area of wall may be covered to safely take thrust of brace.

5. Fig. 57 shows the construction of a support for a water tank in a factory. Design the columns, headers *A* and *C*, also the counters *B*.

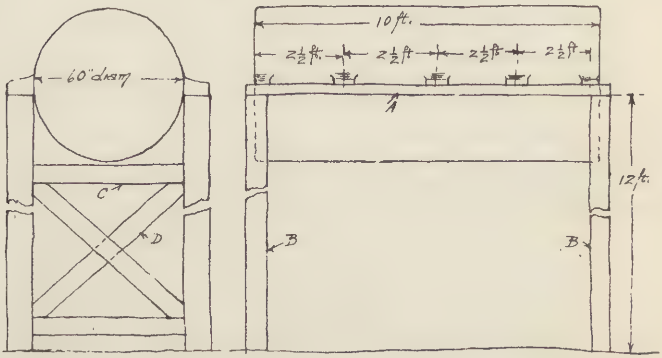


FIG. 55.

6. A wash tank 48″ deep, 60″ long and 36″ wide is to be built for factory use; the pressure is not great, and 1/4″ sheet steel is selected for the stock. Design the riveted joints at the corners, and edges of tank, presenting sketches showing arrangement of parts at these places.

7. The sprinkler system in a factory required the use of an open tank, 15 ft. long, 8 ft. wide and 5 ft. deep; it was made of 1/2″ steel, with 1 1/2″ steel angles 3/8″ thick riveted lengthwise, and across ends horizontally to prevent bulging. Design the riveted joints, and spacing of rivets on the horizontal braces; present sketches illustrating your designs.

8. An acid tank used in a factory has a steel shell 3/8″ thick; it is 12 ft. long, 6 ft. wide, and 4 ft. deep; 1 1/4″ steel

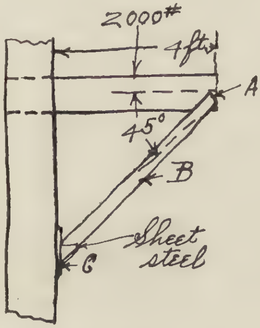


FIG. 56.

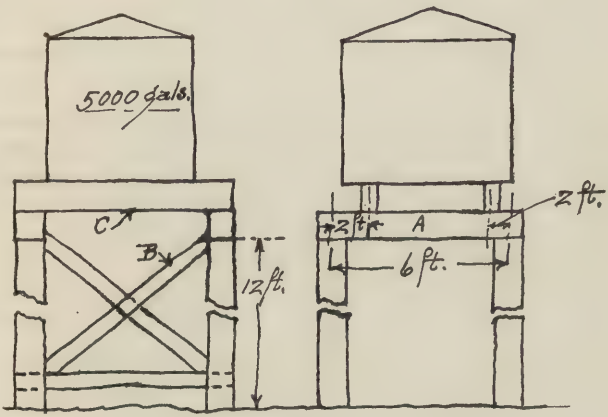


FIG. 57.

angles 1/4″ thick are used as braces on sides and ends; give full specifications for riveted joints and bracing rivets.

9. A cylindrical oil storage tank is to be made of 1/4″ steel;

design the lengthwise and girth seam riveting, presenting sketches of joint arrangement.

10. A cooling tank used in a hardening room is to be made of 5/16″ steel; it is 4 ft. long, 4 ft. wide, and 4 ft. high. Design the riveting for all joints, and illustrate your design with sketches.

11. A tank used in a drip system is of cylindrical form, 5 ft. long, 3 ft. diam. and made of 3/8″ steel. Design all joints, illustrating with sketches.

12. In the protection system of a factory it is decided to make some large semi-circular guards for gears, of 3/16″ steel; such guards are 30″ radius and 15″ long. Give your specifications for the riveted joints, and illustrate with sketches.

13. A coal truck body is made of 1/4″ steel; it is 6 ft. long, 5 ft. wide and 24″ deep; this size necessitates riveted joints in the bottom, and at the edges; present your design of these joints.

14. A tumbling drum used in a factory is to be 4 ft. long, and 3 ft. diam. of 5/16″ steel; it has steel heads and inside of it are riveted 3″ steel angles 1/4″ thick; design the longitudinal seam, riveting for inside angles, and riveting for holding bottom in place. Present necessary sketches.
Answered as an illustrative problem.

15. A small tank 24″ deep and 30″ square is made of 1/4″ steel for use in a glue heating device. Design the corner joints.

16. Design the riveted joints necessary for holding steel angles to I-beam and wall plate called for in problem 4 of this set.

CHAPTER IX.

REINFORCED CONCRETE.

Reinforced concrete is a combination which has come to the industries in comparatively recent years; concrete and cement have been used a great deal for many years past in foundations and similar work; but the placing of steel rods in concrete to take up stress in tension, which is the arrangement of reinforced concrete, is comparatively new; the greatest common error on the part of many persons who have had more or less to do with this material has been the belief that no skill was necessary in putting up concrete construction; no assumption could be more misleading; concrete must be composed of the proper ingredients, carefully mixed, and applied in the successive steps in such a way that there is certainty of a uniting of all the parts into one solid structure; forms must be carefully placed, and the supports for such forms properly designed; further these forms must not be removed until the material is fully able to bear its own weight, while if the concrete is placed in cold weather care of materials in the way of heating before and after placing must be particularly observed. Before proceeding with the study of reinforced concrete, the matter already presented in an earlier chapter on cement and concrete should be reviewed, because all the truths pre-

sented hold with equal force in the handling of concrete in the reinforced form.

In reinforced concrete work the steel is introduced and so placed that it will take up any load causing tension, or bending, while the concrete itself carries the compression, so we see that we are dealing with a composite structure, made up of two entirely different kinds of materials. The position and amount of steel used in such construction bears a very important relation to the strength of the work in hand; at the same time we are dealing with a material which in actual practice, lends itself but little to nicety of calculation, so design has developed along practical lines, using

FIG. 58.

certain formulas which have been deduced, and a liberal factor of safety. Actual experiment shows a marked variation from the results which might be expected if we use even the most complicated formulas, so it is customary with many engineers to use a simple formula, giving results which have been found serviceable in practice; the formulas given in this section are taken or adapted largely from the book entitled "Concrete"[1] by Edward Godfrey, M. Am. Soc. C. E.

Steel in Reinforced Concrete.—The steel used as reinforcement for concrete is not usually of a simple square or round form, because it is apt to slip in the concrete when stress is applied; the bars are variously

[1] Published by the author, Monongahela Bank Building, Pittsburg, Pa.

shaped, but a twisted square bar as shown in fig. 58, does very effective work, and is the only deformed bar which we will consider in this book.

Placing Reinforcement in Forms.—The method of placing the steel in concrete is to fasten it in place by means of wires to the forms so that the reinforcement is in exactly the required position within the forms, after these forms are carefully set. The method is shown in fig. 59, the sketch at *A* showing the method for supporting the reinforcing on a beam and that at *B* and *C* illustrating it for a column; the notes on the plate make the details of setting clear; after the reinforcing is thus placed, the concrete is put in the forms, and when it is sufficiently set such forms are removed; as already mentioned in connection with plain concrete these forms should not be removed in less than one or two weeks for walls, about three weeks for columns and beams, while arch forms should stay in place about a month, assuming that the weather is good; if cold or damp weather is experienced the forms should remain in place for a longer period; concrete should not be subject to its full load in less than from sixty to ninety days after it is completed; after removal of the forms the supporting wires which have been used to carry the reinforcement are cut off close to surface of the concrete.

Columns may be reinforced by using a number of small rods set vertically, and surrounded by "spirals" of wire or rings as shown in fig. 61. The horizontal and vertical reinforcing should be tied together by several turns of binding wire about 1/16″ diam. In the case of cylindrical columns, the reinforcing is set in the form

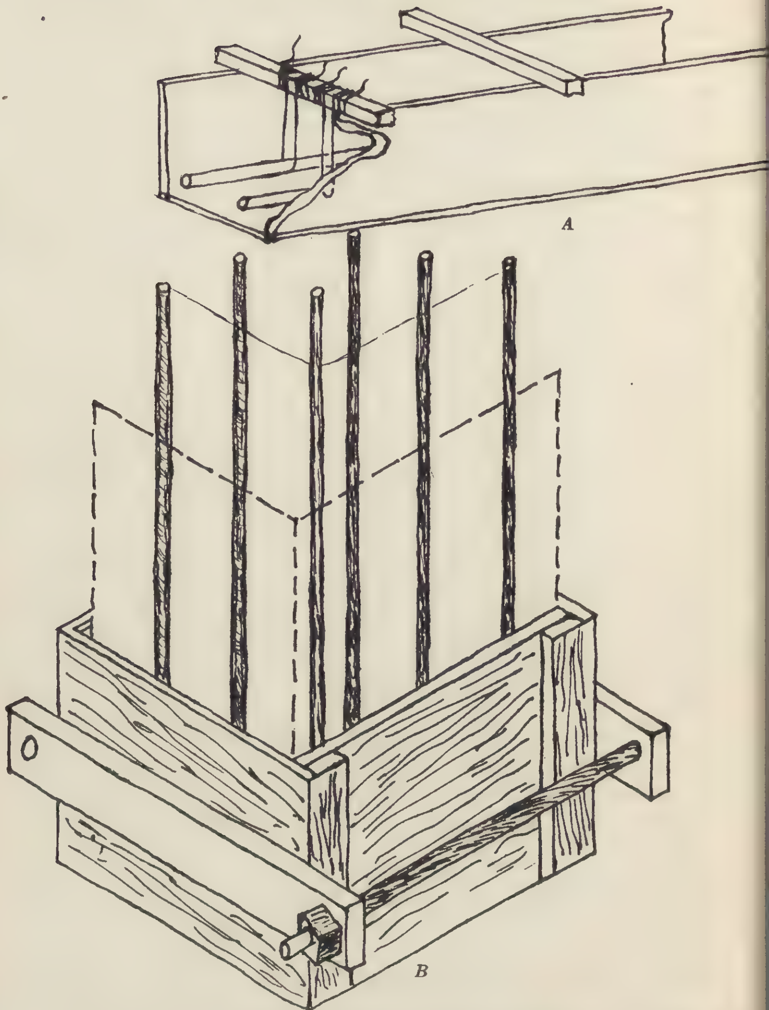


FIG. 59.—*A*, Showing metdod of supporting reinforcing in a beam form while filling with concrete. *B*, Showing method of putting up a column using sectional forms. The first section of form is set here. After filling, the next section of form goes up, as indicated by the dotted lines. This operation is continued until the column is complete.

of a circle, while in the case of square column the reinforcement is set to a square form; proportions for such reinforcement will be taken up later; on the larger jobs, the reinforcing surrounding the vertical bars of

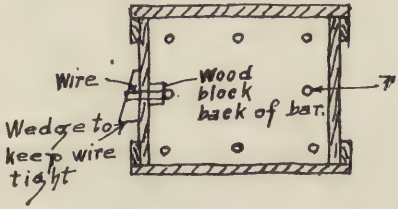


FIG. 60.—Showing method of supporting reinforcing when putting up a column. Wood blocks are removed as each section of column is filled.

a column are coiled to the required form, or welded into rings, as well as squares, but for small jobs it is often necessary to make up reinforcing rings by hand

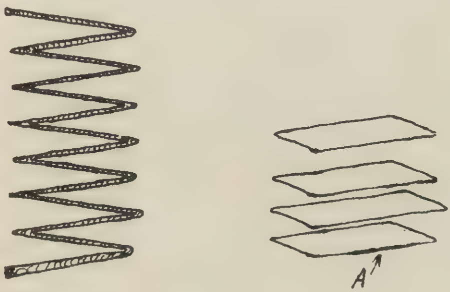


FIG. 61.

and joint by hooking over the ends as shown at fig. 62. This hook should be about ten times the diameter of the reinforcement in length and after jointing up, the ends should be hammered down as indicated and bound

with wire before being put in place in the form. Ties should be made at every joint with vertical reinforcement by means of binding wire as already mentioned.

Materials for Reinforced Concrete.—The materials for reinforced concrete should be a good grade of Portland cement, and an aggregate of crushed stone. The steel should generally be a soft grade, of the open hearth variety; the water should not be taken from sewer connections, nor be dirty, but as clean as that necessary for common domestic use; sand should not

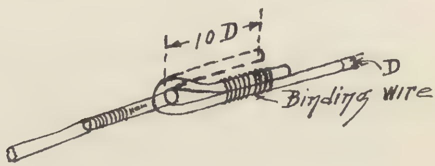


FIG. 62.

be dirty, or mixed with earth, but clean and sharp; the concrete must be thoroughly wet, sufficiently so that it will not remain in a pile; this is particularly important in reinforced work, so that the concrete may closely surround the reinforcing steel; such a condition is not possible if dry concrete is used.

Tieing of Reinforcing Joints.—All joints should be tied by use of binding wire as already mentioned briefly in connection with column work, so there will not be a tendency for the various elements forming the reinforcing to separate; this tying should not be simply one or two turns of binding wire carelessly put on, but of four or five turns and in heavy reinforcing, ten or

twelve, with the ends well twisted together. In running long columns and beams it sometimes becomes necessary to use more than one length of rod, *e.g.*, if we had a 25 ft. beam and the longest rods to be obtained were 10 ft., then we would use three 10 ft. rods; such rods should not be placed end to end in the form, but be lapped over and bound by means of binding wire; such lapping should be about 40 diameters of the rod, that is, if we were using 1/2″ steel as reinforcement, the ends of rods should lap over at least 20″.

Notes on the Setting of Forms.—The forms should be carefully set to the required position, well supported to carry the concrete and any loads which will have to be put upon them while the construction is going on; column forms should not be required to hold beam and floor forms, separate posts being provided for such purpose; it should not be made a practice to put braces to hold the forms for beams, and columns, inside such form; these supports always being placed outside; braces may, however, be put through walls, as has already been described. The spacing of braces for the proper support of forms has already been given on earlier pages, and may be safely followed in reinforced work; the clamps used for column forms being spaced about the same as for walls, will enable one to decide the positions of such clamps as are shown in fig. 59, *B*, when putting up column work.

Design Calculations.—The variation found when we design a beam, and then test it under an actual load, between what a beam is expected to do, and what it really will do, has been previously mentioned; this

variation is so marked that theoretical formulas may have little or no meaning when applied to actual construction, hence no consideration of complicated formulas will be taken up, nor extended theories studied, but we will hold to a line of practical application.

Beam Calculations.—The calculations for beam sizes follow the same process as for similar work in steel or timber, namely, finding the maximum bending moment, equating this to the resisting moment of the beam, then solving for unknown values which determine the size of the beam. The amount of steel which should be placed in a beam for reinforcement is based on the total sectional area and may be taken at "1.25% of such area."[1] This should not be put in one bar, but be divided approximately to meet the following requirements:

*"Round rods spaced at least 3.1416 times diameter apart."

*"Square rods spaced four times diameter apart."

*"Distance from side of beam face to center of round rod 1.57 times diameter of round rod."

*"Distance from beam face to face of square rod one and one-half times the diameter of the rod."

A rule should be made never to place any reinforcing nearer to the bottom of a beam than 1/8 of its depth.

We may well keep in mind the fact, that the steel is not introduced in concrete to care for compressive loads; the concrete itself does this; the steel takes the tension, hence must be placed where it can care for this loading; in a beam then, we would expect to find the steel near the bottom, and in a column near the

[1] Godfrey's "Concrete."

outer face, and as a matter of fact this is the arrangement we meet in practice.

Resisting Moment in Reinforced Beam.—The formula for the resisting moment of a reinforced beam introduces the values of stresses in a composite structure; its practical form, however, presents but two unknown values, breadth and depth of beam, other factors being cared for under a constant as follows

$$*M_r = 354\ BD^2.$$

B = Breadth of beam.

D = Depth of beam.

The value of M_r thus obtained is that which would break the beam; in other words it is the ultimate resisting moment which the beam could exert, and whatever factor of safety we use must be introduced in applying the formula to an actual case of practice; if 10 then we may use M_r as equal to $\frac{354\ BD^2}{10}$.

After finding B and D, the proportion of reinforcement may be taken up as previously mentioned, basing calculation on entire area.

Shear.—The shear must be looked after in this type of beam, with some care, since no greater stress than 50# per sq. in. should be allowed on concrete, in this type of stress; in this connection we recall the fact that shear in a beam is not uniform over its whole sectional area, but is greatest near that section where the neutral line is located; the theory of shear in a beam is somewhat difficult to analyze, but the above simple statement will give a clue to the reason why shear cannot be treated as uniform; the formula giving the safe shearing strength of a concrete beam is:

$$*Z = \frac{2}{3} S_s BD.$$

Z = Total load which beam will sustain in shear.

S_s = Safe shearing strength of concrete in $\# \square''$ (pounds per sq. in.)

B = Breadth of beam in inches.

D = Depth of beam in inches.

The process in design of reinforced beams is, first to determine the size of beam necessary to carry the given load; then add the weight of the beam itself together with the weight of any material used as flooring, which may come on the beam; check design to see that beam is safe to carry the applied load, and its own weight. Godfrey recommends that no beam exceed 1/10 of its span in depth. At the close of the chapter will be found the solution of a design problem, dealing with both beams and columns.

Columns in Reinforced Concrete.—Columns of considerable length should not be put up in concrete; such members are commonly put up in steel, a study of reinforced buildings bringing out very clearly the fact that concrete columns are short. In a considerable amount of concrete building work where a long column is wanted it is common practice to design a steel column to carry the full load, and encase it with concrete, for the fire protecting advantages, such a scheme puts practically no stress on the concrete, the head of the steel column being designed to carry the concrete beams which may rest on it by introducing brackets on which beam ends may rest.

Column Footings.—Columns do not commonly rest

their ends directly on the ground, or floor, because they are not of sufficient area to properly distribute the load, and in the case of steel, timber, or cast iron, footing plates are used which distribute the stress over the masonry or concrete used as a column base; such plates will be found listed in Kidder's Architect's and Builder's Pocket Book.[1] In putting up a concrete column, such a plate is not used, but a footing of reinforced concrete supports the column directly.

Reinforced Footing Design.—We will take up in an elementary practical way the design of such footings, and it may be mentioned that the same method of design is applicable to wall footings. A study of fig. 63 will give us a good idea of the appearance of a footing, such as we are taking up; the width or diameter, if round, must be determined from the nature of the soil on which the footing rests; when a concrete column does not carry a weight directly to the earth, it rests on a beam, or on top of another column, hence we see that footing design is not necessary except in those cases in which the column comes to the ground. Table below will serve as a guide in the application of loads to various kinds of materials, and will be used in later illustrations of design methods.

Loads in tons per sq. ft. which may be safely placed on different kinds of supporting material:

Good firm earth 1 1/2 tons per sq. ft. Use this as a fair average for any kind of solid earth. (Quicksands and muds should not be handled except by experienced engineers.)

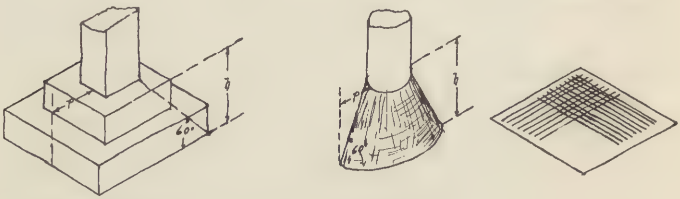
Rip-rap, five tons per sq. ft.

[1] This book is on file in any public library, and in most school libraries.

Ashler masonry, twenty tons per sq. ft.

Brick masonry, five tons per sq. ft.

A footing for a column or wall is really a cantilever, as a little study of fig. 63 will make clear, since we note that the column carries a load to the center of the footing, while the body spreads out to a considerable distance beyond the base of the column; now since, according to principles of mechanics, the earth pushes up just as hard on the bottom of the footing as the column pushes down on the top, we realize that much



Stepped footing Cone footing

FIG. 63.

of the column pressure must be transmitted to the earth by the overhanging part of the footing, acting as a cantilever which is uniformly loaded.

The formula we plan to use gives the height of the footing in terms of the projection, or overhang, as we have termed it, as follows:

$h = .56\ p.\ s.$

s = Safe pressure in tons per sq. ft. on the supporting material; (earth, ashler masonry, rip-rap, etc).

p = Distance of extreme edge of footing from face of column, measured in inches.

h = Height of footing in inches.

From the above we may determine the footing proportions, but we have gathered no information relative to reinforcement; a square twisted rod is recommended here, similar to that in fig. 58.

Such rods are $1/50\ p$ in diameter.

Space same 8.5 diameters apart from center to center.

Locate no nearer than 1/8 depth of footing from bottom.

Angle of footing sides with base 60°, if a cone footing is used.

Column Design.—The next step, now that we have the necessary information concerning the design of footings, is the column; this element is designed on the basis of a direct compressive stress, and after determining an area sufficient for the work, the reinforcement is proportioned and positioned; many vertical members in concrete construction are not more than ten times their diameter in length, but steel reinforcement should not be omitted because of this fact; in concrete construction such members are known as short columns; very long columns should not be attempted in concrete, steel being introduced where such are necessary. The stress in compression which may be used in designing, should be taken at about 400# per sq. inch for 15 diameters in length, and below 10 diameters in length about 500# per sq. in. may be used; use steel columns for anything over 15 diameters in length; the form of reinforcing has been mentioned, pp. 136–38, also tying of reinforcing and proportions should be decided on the following relations:

Proportion of Reinforcement for Columns.—Diameter of reinforcing steel coil, or ring 7/8 diameter of column.

Diameter of steel used as reinforcement, in coils, or rings and for lengthwise reinforcement should be 1/40 diameter of column.

Pitch of circumferential coil, or distance apart for spacing of such rings should be 1/8 diameter of column.

Use eight lengthwise rods in all column reinforcement, equally spaced about, and inside of reinforcing rings.

Illustrating Method of Design for Beams and Columns.

As an illustration of the method of applying in construction, the principles presented above, let us carry through in design the following piece of work:

A delivery pocket for a coal and cinder storage is to carry a total load of 25 T; it is to be supported on four columns, and have a "pitched" floor, details as shown in fig. 64; the columns and headers A are to be of reinforced concrete; what should be the size and reinforcing details of headers, columns and footings?

It is evident that the total load in the pocket will be carried on the two headers A, hence each of these must be designed to carry one-half of 25 T or 12.5 T equals 25,000#; each beam will be 12 ft. long, uniformly loaded, and should be designed under a factor of safety 4 (see Table No. 4). The formula for maximum bending moment in a uniformly loaded beam is:

$$M_B = \frac{1}{8} P_t L_i \qquad \text{(a)}$$

Numerical values for the particular problem we have in hand are:

$$P_t = 25{,}000\#.$$
$$L_i = 144''.$$

The formula for the resisting moment of the reinforced beam is:

$$M_r=\frac{354BD^2}{4} \tag{b}$$

Equating (a) and (b) which must be the case in practice, as we have already seen, we have:

$$\frac{354BD^2}{4}=\frac{1}{8}P_tL_i \tag{d}$$

Introducing numerical values we have for (d)

$$\frac{354BD^2}{4}=\frac{1}{8}\times 25{,}000\times 144$$

Or transposing and dividing we have:

$$BD^2=\frac{4\times 25000\times 144}{354\times 8} \tag{e}$$

$BD^2=5084$, which for round number values we may call 5100; solve by substituting various values for $B \times D$; first try 10×12
we find

$$10\times(12)^2=10\times 144=1440$$

so we see 10×12 is much too small; try 14×20 and we find that $BD^2=5600$.

We have not, however, taken into consideration the weight of the beam; if it is 12 ft. long, and we take concrete as weighing 150# per cu. ft., we have for total beam weight:

$$\frac{\overbrace{14\times 20}^{\text{Area}}\times\overbrace{144}^{\text{length}}}{\underbrace{1728}_{\text{cu. ins. in ft.}}}\times\underbrace{150}_{\text{wt. of one cu. ft. of conc.}}=3500\#$$

This should be added to the total beam load of 25,000# and beam calculations checked, for the new load, and then we will have for (e)

$$BD^2 = \frac{4 \times 28{,}500 \times 144}{354 \times 8}$$

$$BD^2 = 5799\# \quad (5800\#)$$

we now see that the size of the beam must be increased, and we will find 15×20 when tried for $BD^2 = 6000$ and will be chosen.

The reinforcement may now be considered; the total area of such steel reinforcement (see p. 142), is 1.25% of beam area; 1.25% of $15 \times 20 = 3\ 3/4\,\square''$ of steel; the square reinforcing bar already mentioned will be used; requirements for placing this reinforcement may be fiilled thus: let N represent the necessary number of bars for reinforcement, and knowing the width of the beam, which in this case is $15''$, we may deduce a formula which can be used in determining the number of bars to be used as follows:

$$\underbrace{5D}_{\substack{\text{Distance between}\\ \text{corresponding faces}\\ \text{of adjacent rein-}\\ \text{forcing bars.}}} \times \underbrace{N}_{\substack{\text{Number of}\\ \text{reinforc-}\\ \text{ing bars.}}} + \underbrace{(2 \times 1.5D)}_{\substack{\text{Distance of}\\ \text{rod faces}\\ \text{from beam}\\ \text{faces.}}} = \underbrace{15}_{\substack{\text{Width of}\\ \text{beam we}\\ \text{are con-}\\ \text{sidering.}}}$$

or

$$5DN + 3D = 15.$$

We may substitute in this formula until the two members balance. Suppose we try a $1''$ sq. bar for the first and we have

$$5 \times 1 \times N + 3 \times 1 = 15$$

or

$$5N + 3 = 15 \quad . \quad . \quad . \quad . \quad 8N = 15$$

$N = 1\ 7/8$, and it is evident we cannot use a fraction of a bar, so we call $N = 2$.

Two bars, each 1″ in diam. will not, however, give us sufficient steel reinforcement, since we will have but 2 □″ and according to calculations we should have 3 3/4 □″; two bars 1 1/2″ diam. will give us a total steel area of 4.5 □″, and we are ready to specify the location; under directions of p. 142 these must not be nearer to each other than

$4 \times 1.5 = 6''$, nor nearer to the beam faces than

$$1.5 \times 1.5 = 2.25''.$$

If we go over the dimensions we have for total measurement over rods:

6″	+	3″	=	9″
↑		↑		
Distance between rods.		Twice diam. of one rod.		

15″	−	9″	=	6″ or we have 3″ between face of beam and face of each rod.
Total width of beam.				

hence we are within all limitations.

We must now find out whether or not the beam is safe in shear; the reaction at each end of the beam is 6.5 tons, or 13,000#, and this is the load tending to shear the member.

Applying the formula p. 144, for the safe shearing load to which this beam may be subject we have

$$Z = \frac{2}{3} \times 50 \times 15 \times 20 = 10,000\#.$$

Our design is not sufficiently large to care for shear, so we must increase the area as it approaches the columns,

which we may do by increasing the depth at these points until we have

$$13{,}000 = \frac{2}{3} \times 50 \times 15 \times \text{depth},$$

or depth must be 26″. The beam will take the form shown at *b*, fig. 65.

The distance of the reinforcing rods from the bottom of the beam should be $1/8 \times 20'' = 2.5''$, and carried directly across the beam as indicated by the dotted lines in *b*, fig. 65.

As we have 25 T supported on four columns it is evident that each column will carry a load of 6 1/4 T = 12,500#; we will design these on a basis of diameter equal to 1/15 of length, and have:

$1/15 \times 15 = 1$ ft. $= 12''$ diam. of longer column and
$1/15 \times 10 = 10/15$ ft. $= 8''$ diameter of shorter column.

Design on a stress of 400# per sq. in., and each of these columns will carry

$$12 \times 12 \times 400 = 57{,}600\#$$

and

$$8 \times 8 \times 400 = 25{,}600\#$$

safely. We may proceed directly with the reinforcement, as the columns are safe, so far as compressive stresses are concerned.

The reinforcing rings will be square and each:

$$7/8 \times 12 = 10\ 1/2''$$

and

$$7/8 \times 8'' = 7''$$

having the proper lap. (see fig. 62).

The diameter of stock from which these rings will be made is

$$1/40 \times 12 = .3'' \text{ or } 5/16''$$

and

$$1/40 \times 8 = .2'' \text{ or } 1/4''.$$

When calculated values are determined, it is customary practice to take the nearest sixteenth inch size, hence $5/16'' = .312''$ and $1/4'' = .250''$ come nearest to the calculated values above; for lengthwise reinforcement, the diameter of rods will be the same as for the rings in each case, eight rods being used as shown at fig. 60, placed inside the rings; the vertical distance between the reinforcing rings is

$$1/8 \times 12'' = 1\ 1/2''$$
$$1/8 \times 8 \quad = 1''$$

respectively. (If a coil is used this will be the pitch of the "spiral" to which coil is wound.)

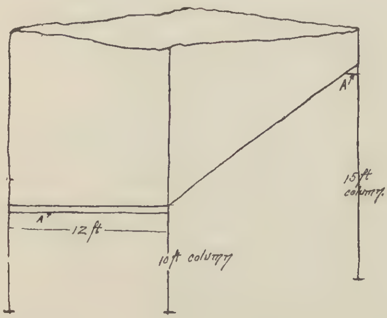


Fig. 64.

Rods can be purchased on the market, which are 10 ft. and 15 ft. long without difficulty, hence, no lapping of reinforcement will be necessary.

The column footings are the next features to be considered, and as this work was placed on firm earth, we may assume a loading of 1 1/2 T per sq. ft. Each column carries 6 1/4 T, hence area at bottom of footing must be

$$\frac{25}{4} \div \frac{3}{2} = 4.1 \text{ sq. ft.}$$

which we may call 4 sq. ft. for practical purposes.

Making the footing 2 ft. sq. the overhang in each case will be:

6″ in the case of 12″ column
and 8″ in the case of 8″ column.

Height of footing according to formula p. 146 is:

$$h = .56 \times 6 \times 1.5 = 5.04'' \text{ or } 5\ 1/4''$$

and

$$h = .56 \times 8 \times 1.5 = 6.72'' \text{ or } 6\ 3/4''.$$

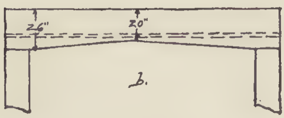


FIG. 65.

FIG. 66.

As to reinforcement of footings, formulas p. 147 give us

$$1/50 \times 6 = .12'' \text{ or } 1/8''$$

and

$$1/50 \times 8 = .16'' \text{ or } 3/16''$$

as rod diameters.

These rods will be spaced respectively:

$$8.5 \times 1/8 = 1''(+) \text{ for } 12'' \text{ column}$$

and

$$8.5 \times 3/16'' = 1.6'' \text{ or } 1\ 5/8'' \text{ for } 8'' \text{ column.}$$

Such rods should be located

$$1/8 \times 5\ 1/4 = 5/8''\ (+)$$

and

$$1/8 \times 6\ 3/4 = 7/8'' \ (-)$$

from bottom of footing.

These footings made square, with two layers of reinforcing, one above the other, and sides standing at an angle of 60° with the horizontal, giving a top smaller than bottom; as the beam A, fig. 64, is 15″ wide and columns 8″ and 12″, it is evident that the columns must be "flared" at the top to give a support over the whole bottom of the beam; the design of one bent is shown complete in fig. 66.

Any of the problems involving columns or beams which have been presented may be used for practice in reinforced concrete, since it is somewhat a matter of choice as to what materials shall be used in these constructions.

Elastic Limits of Materials.

TABLE 1.

(Largely from Trautwine's "Civil Engineers' Pocket-book," Trautwine Company, Philadelphia, Pa.)

Material.	
Ash	4500# □″
White or yellow pine	3300# □″
Spruce	3300# □″
Cast brass	6000# □″
Drawn brass (may be used for *rolled brass*)	16000# □″
Cast copper	6300# □″
Drawn copper (may be used for rolled copper)	10000# □″
Cast iron	4500# □″
Wrought iron	30000# □″
Steel	39000# □″

TABLE 2.

Ultimate strength in lbs. per sq. in. of metals. Taken largely from "Mechanics of Engineering" by Irving P. Church, C. E. Pub. by John Wiley and Sons, New York.

Material.	Tension.	Compression.	Shear.	
Soft steel	80,000	....	70,000	
Hard steel	130,000	200,000	90,000	
Cast iron	30,000	90,000	10,000	quite variable
Wrought iron	45,000	40,000	50,000	

Where no definite information as to compressive strength of a material such as steel or wrought iron is available it may be assumed as about 2/3 of tensile strength.

Malleable iron 30,000#, 50,000#, 10,000#.

TENSILE STRENGTH OF STEEL.

Bessemer-Structural and bar	50,000
Open hearth structural and bar	50,000
Cold rolled steel	75,000
Crucible	95,000
Tool steel	130,000

When you are not certain just what kind of steel you will use in a design, base calculation on general entries of soft and hard as in first section of table. If class is definitely known use second section for steel.

TABLE 2 A.

Values of S_u for use in gearing.

Speed of teeth in feet per minute	100 or less	200	300	600	900	1200	1800	2400
Cast iron.......	8000	6000	4800	4000	3000	2400	2000	1700
Steel..........	20000	15000	12000	10000	7500	6000	5000	4300

From Kent's Engineer's Pocket Book. John Wiley and Sons, N. Y.

TABLE 3.

Ultimate strength of various woods in lbs. per square inch. From Mechanical Engineer's Pocket Book, by William Kent, M. Am. Soc. M. E. John Wiley and Sons, New York.

Wood	Tensile strength	Crushing strength endwise	Crushing strength crosswise	Shearing strength with grain	Shearing strength across grain
Ash..........	12000	6800	3000	500	6200
Oak..........	11000	7000	4000	800	4400
Yellow pine...	13000	8500	2600	300	5500
Spruce.......	10000	4500	1200	250	3200
Hemlock.....	7200	4000	1000	400	2700

Note.—Values in all instances are in whole numbers, rather than as exactly given in table; hemlock is a particularly unreliable wood as sold in the market.

TABLE 4.

Factors of Safety.

Cast iron,	4 for a dead load.
	6 for a live load.
	15 for a load producing shocks.
Steel,	3 for a dead load.
	5 for a live load.
	12 for a load producing shocks.
Timber,	7 for a dead load.
	10 for a live load.
	20 for a load producing shocks.
Brickwork,	20 for a dead load.
	30 for a live load.

Stonework same as brickwork.

Malleable iron and brass same as cast iron.

Wrought iron same as steel.

Reinforced concrete,	4 for a dead load.
Reinforced concrete,	5 for a live load.
Plain concrete,	10 for a dead load.
Plain concrete,	15 for a live load.

TABLE 5.

Ultimate strength of brickwork, stonework and concrete.

All entries are for work which is 3 months old.	Ultimate crushing strength in tons per sq. ft.
Common brick laid in lime mortar,	60
Common brick laid in Rosendale cement mortar,	100
Common brick laid in Portland cement mortar,	150
Rubble walls (stone), Portland cement mortar,	30
Dimension sandstone, Portland cement mortar,	100
Dimension granite, Portland cement mortar	200
Portland cement concrete,	144
Terra cotta (dense),[1]	One half that given for brickwork.
Terra cotta (porous),	Three tenths that given for brickwork.

Ultimate tensile strength of brick and stonework laid in lime mortar may be taken at about 1.5 tons per sq. ft.; and shearing strength about 1/2 of tensile strength. The workmanship is supposed to be well done for these allowances.

Ultimate tensile strength of concrete about 1/10 of compressive strength and shearing strength may be taken about equal to tensile.

[1] National Fire Proofing Co., N. Y. City, issues descriptive pamphlets.

TABLE 6.

Common standard sizes of timber.

In section.

Two inches by
4″–6″–8″–10″–12″–14″–16″

Two and one-half inches by
12″–14″–16″

Three inches by
6″–8″–10″–12″–14″–16″

Four inches by
4″–6″–8″–10″–12″–14″

Six inches by
6″–8″–10″–12″–14″–16″

Eight inches by
8″–10″–12″–14″

Ten inches by
10″–12″–14″–16″

Twelve inches by
12″–14″–16″

Fourteen inches by
14″–16″

In length.

10 ft. 12 ft. 14 ft. 16 ft.

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TABLE 7

Formulas for Properties of Sections Taken from Mechanical Engineer's Pocket Book by Wm. Kent, M. Am. Soc. M. E. Published by John Wiley and Sons, New York.

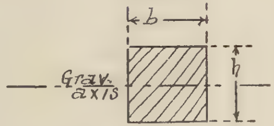
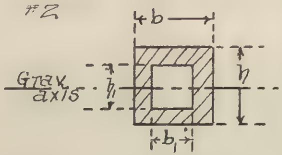
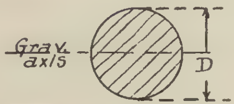
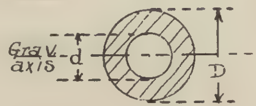
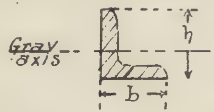
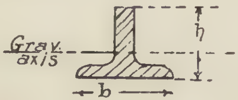
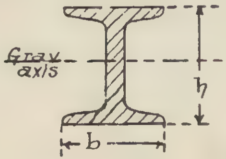
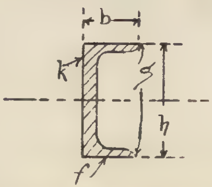
Shape of Section			Moment of Inertia	Section Modulus	Square of least radius of gyration	Least radius of gyration
No. 1.		Solid rectangle	$\frac{bh^3}{12}$	$\frac{bh^2}{6}$	$\frac{(\text{least side})^2}{12}$	$\frac{(\text{least side})^2}{3.46}$
No. 2.		Hollow rectangle	$\frac{bh^3b_1h_1^3}{12}$	$\frac{bh^3b_1h_1^3}{6h}$	$\frac{h^2+h_1^2}{12}$	$\frac{h+h_1}{4.89}$
No. 3.		Solid circle	$\frac{AD^2}{16}$.	$\frac{AD}{8}$	$\frac{D^2}{16}$	$\frac{D}{4}$
No. 4.		Hollow circle A = area of large section and a = area of small	$\frac{AD^2ad^2}{16}$	$\frac{AD^2ad^2}{8D}$	$\frac{D^2+d^2}{16}$	$\frac{D+d}{5.64}$

TABLE 7 Continued

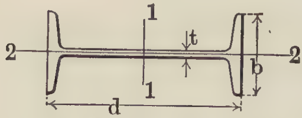
	Shape of Section		Moment of Inertia	Section Modulus	Square of least radius of gyration	Least radius of gyration
No. 5.		Even angle	$\frac{Ah^2}{10.2}$	$\frac{Ah}{7.2}$	$\frac{b^2}{25}$	$\frac{b}{5}$
No. 6.		Even tee	$\frac{Ah^2}{11.1}$	$\frac{Ah}{8}$	$\frac{b^2}{22.5}$	$\frac{b}{4.74}$
No. 7.		I-beam	$\frac{Ah^2}{6.66}$	$\frac{Ah}{3.2}$	$\frac{b^2}{21}$	$\frac{b}{4.58}$
No. 8.		Channel resting on surface f.	$\frac{Ah^2}{7.34}$	$\frac{Ah}{3.67}$	$\frac{b^2}{12.5}$	$\frac{b}{3.54}$

If channel is used with "g" as surface on which to rest use formulas of No. 6 for properties.

Note.—Some of the above formulas give approximate values, but sufficiently accurate for elementary structural work.

TABLE 8

PROPERTIES OF STANDARD I-BEAMS.



Depth of Beam. d Inches.	Weight per Foot. lbs.	Area of Section. A Sq. Ins.	Thickness of Web. t In.	Width of Flange. b Ins.	Moment of Inertia Axis 1–1. I Ins.^{4}	Section Modulus Axis 1–1. S Ins.^{3}	Radius of Gyration Axis 1–1. r Ins.	Moment of Inertia Axis 2–2. I′ Ins.^{4}	Radius of Gyration Axis 2–2. r′ In.
3	5.50	1.63	.17	2.33	2.5	1.7	1.23	.46	.53
3	6.50	1.91	.26	2.42	2.7	1.8	1.19	.53	.52
3	7.50	2.21	.36	2.52	2.9	1.9	1.15	.60	.52
4	7.50	2.21	.19	2.66	6.0	3.0	1.64	.77	.59
4	8.50	2.50	.26	2.73	6.4	3.2	1.59	.85	.58
4	9.50	2.79	.34	2.81	6.7	3.4	1.54	.93	.58
4	10.50	3.09	.41	2.88	7.1	3.6	1.52	1.01	.57
5	9.75	2.87	.21	3.00	12.1	4.8	2.05	1.23	.65
5	12.25	3.60	.36	3.15	13.6	5.4	1.94	1.45	.63
5	14.75	4.34	.50	3.29	15.1	6.1	1.87	1.70	.63
6	12.25	3.61	.23	3.33	21.8	7.3	2.46	1.85	.72
6	14.75	4.34	.35	3.45	24.0	8.0	2.35	2.09	.69
6	17.25	5.07	.47	3.57	26.2	8.7	2.27	2.36	.68
7	15.00	4.42	.25	3.66	36.2	10.4	2.86	2.67	.78
7	17.50	5.15	.35	3.76	39.2	11.2	2.76	2.94	.76
7	20.00	5.88	.46	3.87	42.2	12.1	2.68	3.24	.74
8	18.00	5.33	.27	4.00	56.9	14.2	3.27	3.78	.84
8	20.25	5.96	.35	4.08	60.2	15.0	3.18	4.04	.82
8	22.75	6.69	.44	4.17	64.1	16.0	3.10	4.36	.81
8	25.25	7.43	.53	4.26	68.0	17.0	3.03	4.71	.80

TABLE 8.—Continued

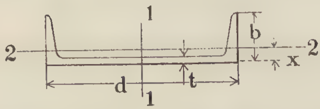
PROPERTIES OF STANDARD I-BEAMS.

Depth of Beam.	Weight per Foot.	Area of Section	Thickness of Web.	Width of Flange.	Moment of Inertia Axis 1-1.	Section Modulus Axis 1-1.	Radius of Gyration Axis 2-2	Moment of Inertia Axis 2-2.	Radius of Gyration Axis 2-2.
d		A	t	b	I	S	r	I′	r′
Inches	lbs.	Sq. Ins.	In.	Ins.	Ins.^{4}	Ins.^{3}	Ins.	Ins.^{4}	Id.
9	21.00	6.31	.29	4.33	84.9	18.9	3.67	5.16	.90
9	25.00	7.35	.41	4.45	91.9	20.4	3.54	5.65	.88
9	30.00	8.82	.57	4.61	101.9	22.6	3.40	6.42	.85
9	35.00	10.29	.73	4.77	111.8	24.8	3.30	7.31	.84
10	25.00	7.37	.31	4.66	122.1	24.4	4.07	6.89	.97
10	30.00	8.82	.45	4.80	134.2	26.8	3.90	7.65	.93
10	35.00	10.29	.60	4.95	146.4	29.3	3.77	8.52	.91
10	40.00	11.76	.75	5.10	158.7	31.7	3.67	9.50	.90
12	31.50	9.26	.35	5.00	215.8	36.0	4.83	9.50	1.01
12	35.00	10.29	.44	5.09	228.3	38.0	4.71	10.07	.99
12	40.00	11.76	.56	5.21	245.9	41.0	4.57	10.95	.96
15	42.00	12.48	.41	5.50	441.8	58.9	5.95	14.62	1.08
15	45.00	13.24	.46	5.55	455.8	60.8	5.87	15.09	1.07
15	50.00	14.71	.56	5.65	483.4	64.5	5.73	16.04	1.04
15	55.00	16.18	.66	5.75	511.0	68.1	5.62	17.06	1.03
15	60.00	17.65	.75	5.84	538.6	71.8	5.52	18.17	1.01

"Cambria Steel," prepared by George E. Thackray, C. E.

TABLE 9

PROPERTIES OF STANDARD CHANNELS.



Depth of Channel d Inches	Weight per Foot Pounds	Area of Section A Sq. Ins.	Thickness of Web t Inch	Width of Flange b Inches	Moment of Inertia Axis 1–1 I Inches⁴	Section Modulus Axis 1–1 S Inches³
3	4.00	1.19	.17	1.41	1.6	1.1
3	5.00	1.47	.26	1.50	1.8	1.2
3	6.00	1.76	.36	1.60	2.1	1.4
4	5.25	1.55	.18	1.58	3.8	1.9
4	6.25	1.84	.25	1.65	4.2	2.1
4	7.25	2.13	.33	1.73	4.6	2.3
5	6.50	1.95	.19	1.75	7.4	3.0
5	9.00	2.65	.33	1.89	8.9	3.5
5	11.50	3.38	.48	2.04	10.4	4.2
6	8.00	2.38	.20	1.92	13.0	4.3
6	10.50	3.09	.32	2.04	15.1	5.0
6	13.00	3.82	.44	2.16	17.3	5.8
6	15.50	4.56	.56	2.28	19.5	6.5
7	9.75	2.85	.21	2.09	21.1	6.0
7	12.25	3.60	.32	2.20	24.2	6.9
7	14.75	4.34	.42	2.30	27.2	7.8
7	17.25	5.07	.53	2.41	30.2	8.6
7	19.75	5.81	.63	2.51	33.2	9.5
8	11.25	3.35	.22	2.26	32.3	8.1
8	13.75	4.04	.31	2.35	36.0	9.0
8	16.25	4.78	.40	2.44	39.9	10.0
8	18.75	5.51	.49	2.53	43.8	11.0
8	21.25	6.25	.58	2.62	47.8	11.9

TABLE 9.—*Continued.*

PROPERTIES OF STANDARD CHANNELS.

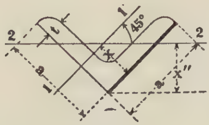
Depth of Channel	Weight per Foot	Area of Section	Thickness of Web	Width of Flange	Moment of Inertia Axis 1–1	Section Modulus Axis 1–1
d		A	t	b	I	S
Inches	Pounds	Sq. Ins.	Inch	Inches	Inches^4	Inches^3
9	13.25	3.89	.23	2.43	47.3	10.5
9	15.00	4.41	.29	2.49	50.9	11.3
9	20.00	5.88	.45	2.65	60.8	13.5
9	25.00	7.35	.61	2.81	70.7	15.7
10	15.00	4.46	.24	2.60	66.9	13.4
10	20.00	5.88	.38	2.74	78.7	15.7
10	25.00	7.35	.53	2.89	91.0	18.2
10	30.00	8.82	.68	3.04	103.2	20.6
10	35.00	10.29	.82	3.18	115.5	23.1
12	20.50	6.03	.28	2.94	128.1	21.4
12	25.00	7.35	.39	3.05	144.0	24.0
12	30.00	8.82	.51	3.17	161.6	26.9
12	35.00	10.29	.64	3.30	179.3	29.9
12	40.00	11.76	.76	3.42	196.9	32.8
15	33.00	9.90	.40	3.40	312.6	41.7
15	35.00	10.29	.43	3.43	319.9	42.7
15	40.00	11.76	.52	3.52	347.5	46.3
15	45.00	13.24	.62	3.62	375.1	50.0
15	50.00	14.71	.72	3.72	402.7	53.7
15	55.00	16.18	.82	3.82	430.2	57.4

"Cambria Steel," prepared by George E. Thackray, C. E.

TABLE 10.

PROPERTIES OF STANDARD ANGLES.

EQUAL LEGS.



Dimensions	Thickness	Weight per Foot	Area of Section	Moment of Inertia Axis 1–1	Section Modulus Axis 1–1	Radius of Gyration Axis 1–1
a × a	t		A	I	S	r
Inches	Inch	Pounds	Sq. Ins.	Inches^4	Inches^3	Inch
¾ × ¾	⅛	.6	.18	.009	.017	.22
¾ × ¾	3/16	.9	.25	.012	.024	.22
1 × 1	⅛	.8	.24	.022	.031	.30
1 × 1	3/16	1.2	.34	.030	.044	.30
1 × 1	¼	1.5	.44	.037	.056	.29
1¼ × 1¼	⅛	1.1	.30	.044	.049	.38
1¼ × 1¼	3/16	1.5	.44	.061	.071	.38
1¼ × 1¼	¼	2.0	.57	.077	.091	.37
1¼ × 1¼	5/16	2.4	.69	.090	.109	.36
1½ × 1½	⅛	1.3	.36	.08	.072	.47
1½ × 1½	3/16	1.8	.53	.11	.104	.46
1½ × 1½	¼	2.4	.69	.14	.134	.45
1½ × 1½	5/16	2.9	.84	.16	.162	.44
1½ × 1½	⅜	3.4	.99	.19	.188	.44
1½ × 1½	7/16	3.9	1.13	.21	.214	.43
1¾ × 1¾	3/16	2.2	.63	.18	.14	.54
1¾ × 1¾	¼	2.8	.82	.23	.19	.53
1¾ × 1¾	5/16	3.4	1.00	.27	.23	.52
1¾ × 1¾	⅜	4.0	1.18	.31	.26	.51
1¾ × 1¾	7/16	4.6	1.34	.35	.30	.51
1¾ × 1¾	½	5.1	1.50	.38	.33	.50

TABLE 10.—*Continued.*

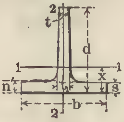
PROPERTIES OF STANDARD ANGLES.

Dimensions	Thickness	Weight per Foot	Area of Section	Moment of Inertia Axis 1–1	Section Modulus Axis 1–1	Radius of Gyration Axis 1–1
a×a	t		A	I	S	r
Inches	Inch	Pounds	Sq. Ins.	Inches⁴	Inches³	Inch
2 ×2	3/16	2.5	.72	.27	.19	.62
2 ×2	1/4	3.2	.94	.35	.25	.61
2 ×2	5/16	4.0	1.16	.42	.30	.60
2 ×2	3/8	4.7	1.36	.48	.35	.59
2 ×2	7/16	5.3	1.56	.54	.40	.59
2 ×2	1/2	6.0	1.75	.59	.45	.58
2½×2½	3/16	3.1	.91	.55	.30	.78
2½×2½	1/4	4.1	1.19	.70	.39	.77
2½×2½	5/16	5.0	1.47	.85	.48	.76
2½×2½	3/8	5.9	1.74	.98	.57	.75
2½×2½	7/16	6.8	2.00	1.11	.65	.75
2½×2½	1/2	7.7	2.25	1.23	.72	.74
2½×2½	9/16	8.5	2.50	1.34	.80	.73
3 ×3	1/4	4.9	1.44	1.24	.58	.93
3 ×3	5/16	6.1	1.78	1.51	.71	.92
3 ×3	3/8	7.2	2.11	1.76	.83	.91
3 ×3	7/16	8.3	2.44	1.99	.95	.91
3 ×3	1/2	9.4	2.75	2.22	1.07	.90
3 ×3	9/16	10.4	3.06	2.43	1.19	.89
3 ×3	5/8	11.5	3.36	2.62	1.30	.88
3 ×3	11/16	12.5	3.66	2.81	1.40	.88

"Cambria Steel," prepared by George E. Thackray, C. E.

TABLE 11.

PROPERTIES OF T-BARS.



EQUAL LEGS.

Dimensions.				Weight per Foot.	Area of Section.	Distance of Center of Gravity from Outside of Flange.	Moment of Inertia Axis 1-1.	Section Modulus Axis 1-1.	Radius of Gyration Axis 1-1.
Width of Flange.	Depth of Bar.	Thickness of Flange.	Thickness of Stem.						
b	d	s to n′	t to t′		A	x	I	S	r
Inches.	Ins.	In.	In.	lbs.	Sq. In.	In.	$In.^4$	$In.^3$	In.
1	1	$\frac{1}{8}$ to $\frac{5}{32}$	$\frac{1}{8}$ to $\frac{5}{32}$	1.0	.27	.29	.02	.03	.30
$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{16}$ to $\frac{7}{32}$	$\frac{5}{32}$ to $\frac{7}{32}$	1.4	.41	.33	.04	.05	.32
$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{3}{16}$ to $\frac{1}{4}$	$\frac{5}{32}$ to $\frac{7}{32}$	1.6	.45	.34	.05	.06	.33
$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{16}$ to $\frac{1}{4}$	$\frac{5}{32}$ to $\frac{1}{4}$	1.7	.48	.36	.06	.07	.35
$1\frac{3}{8}$	$1\frac{3}{8}$	$\frac{3}{16}$ to $\frac{1}{4}$	$\frac{5}{32}$ to $\frac{1}{4}$	1.9	.55	.39	.08	.08	.39
$1\frac{3}{4}$	$1\frac{3}{4}$	$\frac{1}{4}$ to $\frac{5}{16}$	$\frac{1}{4}$ to $\frac{5}{16}$	3.2	.92	.53	.24	.20	.51
2	2	$\frac{1}{4}$ to $\frac{5}{16}$	$\frac{1}{4}$ to $\frac{5}{16}$	3.7	1.07	.59	.37	.26	.59
2	2	$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{5}{16}$ to $\frac{3}{8}$	4.4	1.28	.61	.43	.31	.59
$2\frac{1}{4}$	$2\frac{1}{4}$	$\frac{1}{4}$ to $\frac{5}{16}$	$\frac{1}{4}$ to $\frac{5}{16}$	4.2	1.21	.68	.51	.32	.65
$2\frac{1}{4}$	$2\frac{1}{4}$	$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{5}{16}$ to $\frac{3}{8}$	5.0	1.46	.67	.64	.40	.66
$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{5}{16}$ to $\frac{3}{8}$	5.6	1.63	.73	.87	.49	.74
3	3	$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{5}{16}$ to $\frac{3}{8}$	6.8	1.99	.86	1.58	.74	.90
3	3	$\frac{3}{8}$ to $\frac{7}{16}$	$\frac{3}{8}$ to $\frac{7}{16}$	7.9	2.31	.88	1.82	.86	.90
3	3	$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{1}{2}$ to $\frac{9}{16}$	10.1	2.96	.93	2.27	1.10	.88
$3\frac{1}{2}$	$3\frac{1}{2}$	$\frac{3}{8}$ to $\frac{7}{16}$	$\frac{3}{8}$ to $\frac{7}{16}$	9.3	2.74	.99	3.10	1.23	1.08
4	4	$\frac{3}{8}$ to $\frac{7}{16}$	$\frac{3}{8}$ to $\frac{7}{16}$	10.9	3.19	1.12	4.54	1.58	1.21
4	4	$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{1}{2}$ to $\frac{9}{16}$	13.9	4.08	1.18	5.72	2.03	1.20

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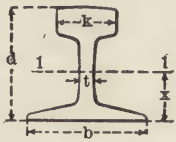
TABLE 12.

PROPERTIES AND PRINCIPAL DIMENSIONS OF STANDARD T-RAILS.



Weight per Yard.	Area.	b	d	k	x	Axis 1–1. Moment of Inertia.	Axis 1–1. Section Modulus.
Pounds.	Sq. Ins.	Inches.	Inches.	Inches.	Inches.	I	S
8	0.78	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{13}{16}$	0.75	0.23	0.31
12	1.18	$1\frac{7}{8}$	$1\frac{7}{8}$	$1\frac{1}{16}$	0.92	0.55	0.58
16	1.57	$2\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{1}{4}$	1.1	1.1	0.95
20	2.00	$2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{3}{8}$	1.2	1.7	1.3
25	2.5	$2\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{1}{2}$	1.3	2.6	1.8
30	2.9	3	3	$1\frac{5}{8}$	1.4	3.6	2.3
35	3.4	$3\frac{1}{4}$	$3\frac{1}{4}$	$1\frac{3}{4}$	1.6	4.9	2.9
40	3.9	$3\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{7}{8}$	1.7	6.6	3.6
45	4.4	$3\frac{11}{16}$	$3\frac{11}{16}$	2	1.8	8.1	4.2
50	4.9	$3\frac{7}{8}$	$3\frac{7}{8}$	$2\frac{1}{8}$	1.9	9.8	4.9
55	5.4	$4\frac{1}{16}$	$4\frac{1}{16}$	$2\frac{1}{4}$	2.0	12.2	5.9
60	5.9	$4\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{3}{8}$	2.1	14.7	6.7
65	6.4	$4\frac{7}{16}$	$4\frac{7}{16}$	$2\frac{13}{32}$	2.2	17.0	7.4
70	6.9	$4\frac{5}{8}$	$4\frac{5}{8}$	$2\frac{7}{16}$	2.2	20.0	8.4
75	7.4	$4\frac{13}{16}$	$4\frac{13}{16}$	$2\frac{15}{32}$	2.3	23.0	9.1
80	7.8	5	5	$2\frac{1}{2}$	2.4	26.7	10.1
85	8.3	$5\frac{3}{16}$	$5\frac{3}{16}$	$2\frac{9}{16}$	2.5	30.5	11.2
90	8.8	$5\frac{3}{8}$	$5\frac{3}{8}$	$2\frac{5}{8}$	2.6	34.4	12.3
95	9.3	$5\frac{9}{16}$	$5\frac{9}{16}$	$2\frac{11}{16}$	2.7	38.6	13.3
100	9.8	$5\frac{3}{4}$	$5\frac{3}{4}$	$2\frac{3}{4}$	2.8	43.4	14.7
150	14.7	6	6	$4\frac{1}{4}$	3.0	69.3	23.1

All sections from 40 lbs. to 100 lbs. both inclusive are Am. Soc. C. E. Standard.
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TABLE 13.
DIMENSIONS OF BOLTS AND NUTS.
Franklin Institute Standard.

Bolts and Threads.					Rough Nuts and Heads.	
Diameter of Bolt.	Threads per Inch.	Diameter at Root of Thread.	Area of Bolt Body.	Area of Bolt at Root of Thread.	Thickness of Nuts.	Thickness of Heads.
Inches.	No.	Inches.	Sq. Ins.	Sq. Ins.	Inches.	Inches.
$\frac{1}{4}$	20	.185	.049	.027	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{5}{16}$	18	.240	.077	.045	$\frac{5}{16}$	$\frac{19}{64}$
$\frac{3}{8}$	16	.294	.110	.068	$\frac{3}{8}$	$\frac{11}{32}$
$\frac{7}{16}$	14	.344	.150	.093	$\frac{7}{16}$	$\frac{25}{64}$
$\frac{1}{2}$	13	.400	.196	.126	$\frac{1}{2}$	$\frac{7}{16}$
$\frac{9}{16}$	12	.454	.249	.162	$\frac{9}{16}$	$\frac{31}{64}$
$\frac{5}{8}$	11	.507	.307	.202	$\frac{5}{8}$	$\frac{17}{32}$
$\frac{3}{4}$	10	.620	.442	.302	$\frac{3}{4}$	$\frac{5}{8}$
$\frac{7}{8}$	9	.731	.601	.420	$\frac{7}{8}$	$\frac{23}{32}$
1	8	.837	.785	.550	1	$\frac{13}{16}$
$1\frac{1}{8}$	7	.940	.994	.694	$1\frac{1}{8}$	$\frac{29}{32}$
$1\frac{1}{4}$	7	1.065	1.227	.893	$1\frac{1}{4}$	1
$1\frac{3}{8}$	6	1.160	1.485	1.057	$1\frac{3}{8}$	$1\frac{3}{32}$
$1\frac{1}{2}$	6	1.284	1.767	1.295	$1\frac{1}{2}$	$1\frac{3}{16}$
$1\frac{5}{8}$	$5\frac{1}{2}$	1.389	2.074	1.515	$1\frac{5}{8}$	$1\frac{9}{32}$
$1\frac{3}{4}$	5	1.490	2.405	1.744	$1\frac{3}{4}$	$1\frac{3}{8}$
$1\frac{7}{8}$	5	1.615	2.761	2.048	$1\frac{7}{8}$	$1\frac{15}{32}$
2	$4\frac{1}{2}$	1.712	3.142	2.302	2	$1\frac{9}{16}$
$2\frac{1}{4}$	$4\frac{1}{2}$	1.962	3.976	3.023	$2\frac{1}{4}$	$1\frac{3}{4}$
$2\frac{1}{2}$	4	2.175	4.909	3.715	$2\frac{1}{2}$	$1\frac{15}{16}$
$2\frac{3}{4}$	4	2.425	5.940	4.619	$2\frac{3}{4}$	$2\frac{1}{8}$
3	$3\frac{1}{2}$	2.629	7.069	5.428	3	$2\frac{5}{16}$
$3\frac{1}{4}$	$3\frac{1}{2}$	2.879	8.296	6.510	$3\frac{1}{4}$	$2\frac{1}{2}$
$3\frac{1}{2}$	$3\frac{1}{4}$	3.100	9.621	7.548	$3\frac{1}{2}$	$2\frac{11}{16}$
$3\frac{3}{4}$	3	3.317	11.045	8.641	$3\frac{3}{4}$	$2\frac{7}{8}$
4	3	3.567	12.566	9.993	4	$3\frac{1}{16}$
$4\frac{1}{4}$	$2\frac{7}{8}$	3.798	14.186	11.329	$4\frac{1}{4}$	$3\frac{1}{4}$
$4\frac{1}{2}$	$2\frac{3}{4}$	4.028	15.904	12.743	$4\frac{1}{2}$	$3\frac{7}{16}$
$4\frac{3}{4}$	$2\frac{5}{8}$	4.255	17.721	14.220	$4\frac{3}{4}$	$3\frac{5}{8}$
5	$2\frac{1}{2}$	4.480	19.635	15.763	5	$3\frac{13}{16}$
$5\frac{1}{4}$	$2\frac{1}{2}$	4.730	21.648	17.572	$5\frac{1}{4}$	4
$5\frac{1}{2}$	$2\frac{3}{8}$	4.953	23.758	19.267	$5\frac{1}{2}$	$4\frac{3}{16}$
$5\frac{3}{4}$	$2\frac{3}{8}$	5.203	25.967	21.262	$5\frac{3}{4}$	$4\frac{3}{8}$
6	$2\frac{1}{4}$	5.423	28.274	23.098	6	$4\frac{9}{16}$

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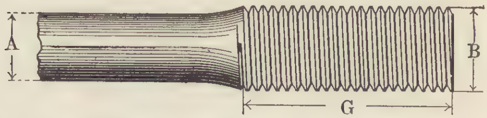
Bolts and nuts are put on the market in standard sizes; a study of this table shows us that for a given diameter there are a certain number of threads per in. used, that the body of the bolt and section at bottom of thread have certain areas, and heads of bolts as well as nuts have given standard thicknesses; all of these values are necessary in design involving use of bolts and nuts in constructive work.

TABLE 14.

UPSET SCREW ENDS FOR ROUND BARS.



Diameter of Bar. A	Area of Body of Bar.	Diameter of Screw. B	Length of Upset. G	Area at Root of Thread.	Number of Threads per Inch.
Inch.	Sq. Ins.	Inches.	Inches.	Sq. Ins.	
$\frac{1}{2}$	.196	$\frac{3}{4}$	$4\frac{1}{4}$	.302	10
$\frac{9}{16}$	.249	$\frac{3}{4}$	$4\frac{1}{4}$	.302	10
$\frac{5}{8}$	.307	$\frac{7}{8}$	$4\frac{1}{2}$	.420	9
$\frac{11}{16}$	.371	1	$4\frac{1}{2}$	.550	8
$\frac{3}{4}$	.442	1	$4\frac{1}{2}$	.550	8
$\frac{13}{16}$	.519	$1\frac{1}{8}$	$4\frac{3}{4}$	.694	7
$\frac{7}{8}$	.601	$1\frac{1}{4}$	$4\frac{3}{4}$	.893	7
$\frac{15}{16}$	.690	$1\frac{1}{4}$	$4\frac{3}{4}$	.893	7
1	.785	$1\frac{3}{8}$	5	1.057	6
$1\frac{1}{16}$	.887	$1\frac{3}{8}$	5	1.057	6
$1\frac{1}{8}$	.994	$1\frac{1}{2}$	5	1.295	6
$1\frac{3}{16}$	1.108	$1\frac{1}{2}$	5	1.295	6
$1\frac{1}{4}$	1.227	$1\frac{5}{8}$	$5\frac{1}{4}$	1.515	$5\frac{1}{2}$
$1\frac{5}{16}$	1.353	$1\frac{3}{4}$	$5\frac{1}{4}$	1.744	5
$1\frac{3}{8}$	1.485	$1\frac{3}{4}$	$5\frac{1}{4}$	1.744	5
$1\frac{7}{16}$	1.623	$1\frac{7}{8}$	$5\frac{1}{2}$	2.048	5
$1\frac{1}{2}$	1.767	2	$5\frac{1}{2}$	2.302	$4\frac{1}{2}$
$1\frac{9}{16}$	1.918	2	$5\frac{1}{2}$	2.302	$4\frac{1}{2}$
$1\frac{5}{8}$	2.074	$2\frac{1}{8}$	$5\frac{3}{4}$	2.650	$4\frac{1}{2}$
$1\frac{11}{16}$	2.237	$2\frac{1}{8}$	$5\frac{3}{4}$	2.650	$4\frac{1}{2}$
$1\frac{3}{4}$	2.405	$2\frac{1}{4}$	$5\frac{3}{4}$	3.023	$4\frac{1}{2}$
$1\frac{13}{16}$	2.580	$2\frac{1}{4}$	$5\frac{3}{4}$	3.023	$4\frac{1}{2}$
$1\frac{7}{8}$	2.761	$2\frac{3}{8}$	6	3.419	$4\frac{1}{2}$
$1\frac{15}{16}$	2.948	$2\frac{1}{2}$	6	3.715	4
2	3.142	$2\frac{1}{2}$	6	3.715	4
$2\frac{1}{16}$	3.341	$2\frac{5}{8}$	$6\frac{1}{4}$	4.155	4
$2\frac{1}{8}$	3.547	$2\frac{5}{8}$	$6\frac{1}{4}$	4.155	4
$2\frac{3}{16}$	3.758	$2\frac{3}{4}$	$6\frac{1}{4}$	4.619	4
$2\frac{1}{4}$	3.976	$2\frac{7}{8}$	$6\frac{1}{2}$	5.108	4

TABLE 14.—*Continued.*

UPSET SCREW ENDS FOR ROUND BARS.

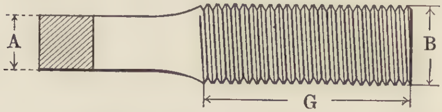
Diameter of Bar. A	Area of Body of Bar.	Diameter of Screw. B	Length of Upset. C	Area at Root of Thread.	Number of Threads per Inch.
Inch.	Sq. Ins.	Inches.	Inches.	Sq. Ins.	
$2\frac{5}{16}$	4.200	$2\frac{7}{8}$	$6\frac{1}{2}$	5.108	4
$2\frac{3}{8}$	4.430	3	$6\frac{1}{2}$	5.428	$3\frac{1}{2}$
$2\frac{7}{16}$	4.666	$3\frac{1}{8}$	$6\frac{3}{4}$	5.957	$3\frac{1}{2}$
$2\frac{1}{2}$	4.909	$3\frac{1}{8}$	$6\frac{3}{4}$	5.957	$3\frac{1}{2}$
$2\frac{9}{16}$	5.157	$3\frac{1}{4}$	$6\frac{3}{4}$	6.510	$3\frac{1}{2}$
$2\frac{5}{8}$	5.412	$3\frac{1}{4}$	$6\frac{3}{4}$	6.510	$3\frac{1}{2}$
$2\frac{11}{16}$	5.673	$3\frac{3}{8}$	7	7.087	$3\frac{1}{2}$
$2\frac{3}{4}$	5.940	$3\frac{3}{8}$	7	7.087	$3\frac{1}{2}$
$2\frac{13}{16}$	6.213	$3\frac{1}{2}$	7	7.548	$3\frac{1}{4}$
$2\frac{7}{8}$	6.492	$3\frac{5}{8}$	$7\frac{1}{4}$	8.171	$3\frac{1}{4}$
$2\frac{15}{16}$	6.777	$3\frac{5}{8}$	$7\frac{1}{4}$	8.171	$3\frac{1}{4}$
3	7.069	$3\frac{3}{4}$	$7\frac{1}{4}$	8.641	3

"Cambria Steel," prepared by George E. Thackray, C. E.

These bars are used in places to take tension; they may be used in small cranes, and as "counterbraces" in stands or platform supports; both round and square type are available, and may be made in the forge shop or purchased on the market.

TABLE 15.

UPSET SCREW ENDS FOR SQUARE BARS.



Side of Square Bar. A	Area of Body of Bar.	Diameter of Screw. B	Length of Upset. G	Area at Root of Thread.	Number of Threads per Inch.
Inch.	Sq. Ins.	Inches.	Inches.	Sq. Ins.	
$\frac{1}{2}$	.250	$\frac{3}{4}$	$4\frac{1}{4}$	.302	10
$\frac{9}{16}$	.316	$\frac{7}{8}$	$4\frac{1}{2}$	.420	9
$\frac{5}{8}$	.391	1	$4\frac{1}{2}$	.550	8
$\frac{11}{16}$	.473	1	$4\frac{1}{2}$	.550	8
$\frac{3}{4}$	.563	$1\frac{1}{8}$	$4\frac{3}{4}$	.694	7
$\frac{13}{16}$	.660	$1\frac{1}{4}$	$4\frac{3}{4}$	.893	7
$\frac{7}{8}$	.766	$1\frac{3}{8}$	5	1.057	6
$\frac{15}{16}$	.879	$1\frac{3}{8}$	5	1.057	6
1	1.000	$1\frac{1}{2}$	5	1.295	6
$1\frac{1}{16}$	1.129	$1\frac{5}{8}$	$5\frac{1}{4}$	1.515	$5\frac{1}{2}$
$1\frac{1}{8}$	1.266	$1\frac{5}{8}$	$5\frac{1}{4}$	1.515	$5\frac{1}{2}$
$1\frac{3}{16}$	1.410	$1\frac{3}{4}$	$5\frac{1}{4}$	1.744	5
$1\frac{1}{4}$	1.563	$1\frac{7}{8}$	$5\frac{1}{2}$	2.048	5
$1\frac{5}{16}$	1.723	$1\frac{7}{8}$	$5\frac{1}{2}$	2.048	5
$1\frac{3}{8}$	1.891	2	$5\frac{1}{2}$	2.302	$4\frac{1}{2}$
$1\frac{7}{16}$	2.066	$2\frac{1}{8}$	$5\frac{3}{4}$	2.650	$4\frac{1}{2}$
$1\frac{1}{2}$	2.250	$2\frac{1}{8}$	$5\frac{3}{4}$	2.650	$4\frac{1}{2}$
$1\frac{9}{16}$	2.441	$2\frac{1}{4}$	$5\frac{3}{4}$	3.023	$4\frac{1}{2}$
$1\frac{5}{8}$	2.641	$2\frac{3}{8}$	6	3.419	$4\frac{1}{2}$
$1\frac{11}{16}$	2.848	$2\frac{3}{8}$	6	3.419	$4\frac{1}{2}$
$1\frac{3}{4}$	3.063	$2\frac{1}{2}$	6	3.715	4
$1\frac{13}{16}$	3.285	$2\frac{5}{8}$	$6\frac{1}{4}$	4.155	4
$1\frac{7}{8}$	3.516	$2\frac{5}{8}$	$6\frac{1}{4}$	4.155	4
$1\frac{15}{16}$	3.754	$2\frac{3}{4}$	$6\frac{1}{4}$	4.619	4
2	4.000	$2\frac{7}{8}$	$6\frac{1}{2}$	5.108	4
$2\frac{1}{16}$	4.254	$2\frac{7}{8}$	$6\frac{1}{2}$	5.108	4
$2\frac{1}{8}$	4.516	3	$6\frac{1}{2}$	5.428	$3\frac{1}{2}$
$2\frac{3}{16}$	4.785	$3\frac{1}{8}$	$6\frac{3}{4}$	5.957	$3\frac{1}{2}$
$2\frac{1}{4}$	5.063	$3\frac{1}{8}$	$6\frac{3}{4}$	5.957	$3\frac{1}{2}$

TABLE 15.—*Continued.*

UPSET SCREW ENDS FOR SQUARE BARS.

Side of Square Bar. A Inch.	Area of Body of Bar. Sq Ins.	Diameter of Screw. B Inches.	Length of Upset. G Inches.	Area at Root of Thread. Sq. Ins.	Number of Threads per Inch.
$2\frac{5}{16}$	5.348	$3\frac{1}{4}$	$6\frac{3}{4}$	6.510	$3\frac{1}{2}$
$2\frac{3}{8}$	5.641	$3\frac{3}{8}$	7	7.087	$3\frac{1}{2}$
$2\frac{7}{16}$	5.941	$3\frac{3}{8}$	7	7.087	$3\frac{1}{2}$
$2\frac{1}{2}$	6.250	$3\frac{1}{2}$	7	7.548	$3\frac{1}{4}$
$2\frac{9}{16}$	6.566	$3\frac{5}{8}$	$7\frac{1}{4}$	8.171	$3\frac{1}{4}$
$2\frac{5}{8}$	6.891	$3\frac{5}{8}$	$7\frac{1}{4}$	8.171	$3\frac{1}{4}$
$2\frac{11}{16}$	7.223	$3\frac{3}{4}$	$7\frac{1}{4}$	8.641	3
$2\frac{3}{4}$	7.563	$3\frac{7}{8}$	$7\frac{1}{2}$	9.305	3
$2\frac{13}{16}$	7.910	$3\frac{7}{8}$	$7\frac{1}{2}$	9.305	3
$2\frac{7}{8}$	8.266	4	$7\frac{1}{2}$	9.993	3
$2\frac{15}{16}$	8.629	$4\frac{1}{8}$	$7\frac{1}{2}$	10.706	3
3	9.000	$4\frac{1}{8}$	$7\frac{3}{4}$	10.706	3

"Cambria Steel," prepared by George E. Thackray, C. E.

These bars are used in places to take tension; they may be used in small cranes, and as "counterbraces" in stands or platform supports; both round and square type are available. and may be made in the forge shop or purchased on the market.

TABLE 16.

LENGTH OF RIVETS REQUIRED FOR VARIOUS GRIPS INCLUDING AMOUNT NECESSARY TO FORM ONE HEAD.

Grip of Rivet in Inches.	Diameter of Rivet in Inches.							
	¼″	⅜″	½″	⅝″	¾″	⅞″	1″	1⅛″
½	1	1¼	1½	1¾	1⅞	2	2⅛	2¼
⅝	1⅛	1⅜	1⅝	1⅞	2	2⅛	2¼	2⅜
¾	1¼	1½	1¾	2	2⅛	2¼	2⅜	2½
⅞	1⅜	1⅝	1⅞	2⅛	2¼	2⅜	2½	2⅝
1	1½	1¾	2	2¼	2⅜	2½	2⅝	2¾
1⅛	1⅝	1⅞	2⅛	2⅜	2½	2⅝	2¾	2⅞
1¼	1¾	2	2¼	2½	2⅝	2¾	2⅞	3
1⅜	1⅞	2⅛	2⅜	2⅝	2⅞	3	3	3⅛
1½	2	2¼	2½	2¾	3	3⅛	3⅛	3¼
1⅝	2⅛	2⅜	2⅝	2⅞	3⅛	3¼	3¼	3½
1¾	2¼	2½	2¾	3	3¼	3⅜	3½	3⅝
1⅞	2⅜	2⅝	2⅞	3¼	3⅜	3½	3⅝	3¾
2	2½	2¾	3⅛	3⅜	3½	3⅝	3¾	3⅞
2⅛	2⅝	2⅞	3¼	3½	3⅝	3¾	3⅞	4
2¼	2¾	3	3⅜	3⅝	3¾	3⅞	4	4⅛
2⅜	2⅞	3⅛	3½	3¾	3⅞	4	4⅛	4¼
2½	3	3¼	3⅝	3⅞	4	4⅛	4¼	4⅜
2⅝	3⅛	3½	3¾	4	4⅛	4¼	4⅜	4½
2¾	3¼	3⅝	3⅞	4⅛	4¼	4⅜	4½	4⅝
2⅞	3⅜	3¾	4	4¼	4⅜	4½	4⅝	4¾
3	3½	3⅞	4⅛	4⅜	4½	4⅝	4¾	4⅞
3⅛	3⅝	4	4¼	4½	4¾	4¾	5	5
3¼	3¾	4⅛	4⅜	4¾	4⅞	5	5⅛	5¼
3⅜	3⅞	4¼	4½	4⅞	5	5⅛	5¼	5⅜
3½	4	4⅜	4⅝	5	5⅛	5¼	5⅜	5½
3⅝	4⅛	4½	4¾	5⅛	5¼	5⅜	5½	5⅝
3¾	4¼	4⅝	4⅞	5¼	5⅜	5½	5⅝	5¾
3⅞	4⅜	4¾	5	5⅜	5½	5⅝	5¾	5⅞
4	4½	4⅞	5⅛	5½	5⅝	5¾	5⅞	6
4⅛	4⅝	5	5¼	5⅝	5¾	5⅞	6	6⅛
4¼	4¾	5⅛	5½	5¾	5⅞	6	6⅛	6¼
4⅜	4⅞	5¼	5⅝	5⅞	6	6⅛	6¼	6⅜
4½	5	5⅜	5¾	6	6⅛	6¼	6⅜	6½

TABLE 16.—*Continued.*

LENGTH OF RIVETS REQUIRED FOR VARIOUS GRIPS INCLUDING AMOUNT NECESSARY TO FORM ONE HEAD.

Grip of Rivet in Inches.	Diameter of Rivet in Inches.							
	$\frac{1}{4}''$	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{3}{4}''$	$\frac{7}{8}''$	$1''$	$1\frac{1}{8}''$
$4\frac{5}{8}$	$5\frac{1}{8}$	$5\frac{1}{2}$	$5\frac{7}{8}$	$6\frac{1}{8}$	$6\frac{1}{4}$	$6\frac{3}{8}$	$6\frac{1}{2}$	$6\frac{5}{8}$
$4\frac{3}{4}$	$5\frac{1}{4}$	$5\frac{5}{8}$	6	$6\frac{1}{4}$	$6\frac{1}{2}$	$6\frac{5}{8}$	$6\frac{3}{4}$	$6\frac{3}{4}$
$4\frac{7}{8}$	$5\frac{3}{8}$	$5\frac{3}{4}$	$6\frac{1}{8}$	$6\frac{1}{2}$	$6\frac{5}{8}$	$6\frac{3}{4}$	$6\frac{7}{8}$	$6\frac{7}{8}$
5	$5\frac{1}{2}$	$5\frac{7}{8}$	$6\frac{1}{4}$	$6\frac{5}{8}$	$6\frac{3}{4}$	$6\frac{7}{8}$	7	7
$5\frac{1}{8}$	$5\frac{5}{8}$	6	$6\frac{3}{8}$	$6\frac{3}{4}$	$6\frac{7}{8}$	7	$7\frac{1}{8}$	$7\frac{1}{8}$
$5\frac{1}{4}$	$5\frac{3}{4}$	$6\frac{1}{8}$	$6\frac{1}{2}$	$6\frac{7}{8}$	7	$7\frac{1}{8}$	$7\frac{1}{4}$	$7\frac{1}{4}$
$5\frac{3}{8}$	$5\frac{7}{8}$	$6\frac{1}{4}$	$6\frac{5}{8}$	7	$7\frac{1}{8}$	$7\frac{1}{4}$	$7\frac{3}{8}$	$7\frac{3}{8}$
$5\frac{1}{2}$	6	$6\frac{3}{8}$	$6\frac{3}{4}$	$7\frac{1}{8}$	$7\frac{1}{4}$	$7\frac{3}{8}$	$7\frac{1}{2}$	$7\frac{1}{2}$
$5\frac{5}{8}$	$6\frac{1}{8}$	$6\frac{1}{2}$	$6\frac{7}{8}$	$7\frac{1}{4}$	$7\frac{3}{8}$	$7\frac{1}{2}$	$7\frac{5}{8}$	$7\frac{5}{8}$
$5\frac{3}{4}$	$6\frac{1}{4}$	$6\frac{3}{4}$	7	$7\frac{3}{8}$	$7\frac{5}{8}$	$7\frac{5}{8}$	$7\frac{3}{4}$	$7\frac{3}{4}$
$5\frac{7}{8}$	$6\frac{3}{8}$	$6\frac{7}{8}$	$7\frac{1}{8}$	$7\frac{1}{2}$	$7\frac{3}{4}$	$7\frac{3}{4}$	$7\frac{7}{8}$	$7\frac{7}{8}$
6	$6\frac{1}{2}$	7	$7\frac{1}{4}$	$7\frac{5}{8}$	$7\frac{7}{8}$	$7\frac{7}{8}$	8	$8\frac{1}{8}$
Amount in Inches to be subtracted from above lengths for Countersunk Heads.								
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$

"Cambria Steel," prepared by George E. Thackray, C. E.

The beginner is at a loss to know what rivet length he should select to hold a certain thickness of plate in joint, and have it "head up" properly. This table gives such information for button and countersunk heads.

TABLE 17.

WEIGHTS OF VARIOUS SUBSTANCES.

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches. Weight of One Cubic Foot, 62.355 Pounds.	Average Weight of One Cubic Foot. Pounds.
Air, atmospheric at 60 degrees F., under pressure of one atmosphere, or 14.7 pounds per square inch, weighs $\frac{1}{815}$th as much as water	.0765
Aluminum	162
Anthracite of Penna	93.5
Anthracite, broken, of any size, loose	52 to 56
Anthracite, broken, moderately shaken	56 to 60
Anthracite, broken, heaped bushel, loose, 77 to 83 pounds	....
Anthracite, broken, a ton loose occupies 40 to 43 cubic feet	....
Antimony, cast	418
Antimony, native	416
Ash, perfectly dry	47
Ash, American White	38
Ashes of soft coal, solidly packed	40 to 45
Asphaltum, 1 to 1.8	87.3
Brass (copper and zinc), cast	504
Brass, rolled	524
Brick, best pressed	150
Brick, common and hard	125
Brick, soft inferior	100
Brickwork, pressed brick, fine joints	140
Brickwork, medium quality	125
Brickwork, coarse, inferior, soft	100
Brickwork, at 125 pounds per cubic foot, 1 cubic yard equals 1.507 tons, and 17.92 cubic feet equal 1 ton	....
Bronze, copper 8, tin 1 (gun metal)	529
Cement, hydraulic. American, Rosendale, ground and loose	56
Cement, hydraulic. American, Rosendale, U. S. struck bush., 70 pounds	....
Cement, hydraulic. American, Rosendale, Louisville bushel, 62 pounds	....
Cement, hydraulic. American, Cumberland, ground, loose.	65
Cement, hydraulic. American, Cumberland, ground, thoroughly shaken	85

TABLE 17.—*Continued.*

WEIGHTS OF VARIOUS SUBSTANCES.—Continued.

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches. Weight of One Cubic Foot, 62.355 Pounds.	Average Weight of One Cubic Foot. Pounds.
Cement, hydraulic. English Portland (U. S. struck bushel, 100 to 128)	81 to 102
Cement, hydraulic. English Portland, a barrel, 400 to 430 pounds	.....
Cement, hydraulic. American Portland, loose	88
Cement, hydraulic. American Portland, thoroughly shaken	110
Charcoal of pines and oaks	15 to 30
Chalk	156
Cherry, perfectly dry	42
Clay, potters', dry	119
Clay, dry in lump, loose	63
Coal, bituminous, solid	84
Coal, bituminous, solid, Cambria Co., Pa	79 to 84
Coal, bituminous, broken, of any size, loose	47 to 52
Coal, bituminous, moderately shaken	51 to 56
Coal, bituminous, a heaped bushel, loose, 70 to 78	.....
Coal, bituminous, 1 ton occupies 43 to 48 cubic feet	.....
Coke, loose, good quality	23 to 32
Coke, loose, a heaped bushel, 35 to 42	.....
Coke, 1 ton occupies 80 to 97 cubic feet	.....
Corundum, pure, 3.8 to 4	.....
Copper, cast	542
Copper, rolled	555
Cork, dry	15
Earth, common loam, perfectly dry, loose	72 to 80
Earth, common loam, perfectly dry, shaken	82 to 92
Earth, common loam, perfectly dry, rammed	90 to 100
Earth, common loam, slightly moist, loose	70 to 76
Earth, common loam, more moist, loose	66 to 68
Earth, common loam, more moist, shaken	75 to 90
Earth, common loam, more moist, packed	90 to 100
Earth, common loam, as soft flowing mud	104 to 112
Earth, common loam, as soft flowing mud well pressed	110 to 120
Elm, perfectly dry	35
Flint	162

TABLE 17.—*Continued.*

WEIGHTS OF VARIOUS SUBSTANCES.—Continued.

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches. Weight of One Cubic Foot, 62.355 Pounds.	Average Weight of One Cubic Foot. Pounds.
Glass	186
Glass, common window	157
Gneiss, common	168
Gneiss, in loose piles	96
Gold, cast, pure or 24 karat	1204
Gold, pure, hammered	1217
Granite	170
Greenstone	187
Gypsum, plaster of Paris	141.6
Hickory, perfectly dry	53
Ice	57.4
Iron	446
Iron, grey foundry, cold	450
Iron, grey foundry, molten	433
Iron, wrought	480
Lead, commercial	709.6
Lignumvitæ (dry)	41 to 83
Limestone and marble	164.4
Lime, quick	95
Lime, quick, ground, well shaken, per struck bushel 80 pounds	64
Lime, quick, ground, thoroughly shaken, per struck bushel 93¾ pounds	75
Locust	44
Mahogany, Spanish, dry	53
Mahogany, Honduras, dry	35
Maple, dry	49
Marble (see Limestone).	
Masonry of granite or limestone, well-dressed	165
Masonry of granite, well-scabbled mortar rubble, about ⅕ of mass will be mortar	154
Masonry of granite, well-scabbled dry rubble	138
Masonry of granite, roughly scabbled mortar rubble, about ¼ to ⅓ of mass will be mortar	150
Masonry of granite, scabbled dry rubble	125

TABLE 17.—*Continued.*

WEIGHTS OF VARIOUS SUBSTANCES.—Continued.

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches. Weight of One Cubic Foot, 62.355 Pounds.	Average Weight of One Cubic Foot. Pounds.
Masonry of sandstone, $\frac{1}{8}$ less than granite	....
Masonry of brickwork (see Brickwork).	
Mercury, at 32 degrees Fah	849
Mica, 2.75 to 3.1	183
Mortar, hardened	103
Mud, dry, close	80 to 110
Mud, wet, moderately pressed	110 to 130
Mud, wet, fluid	104 to 120
Oak, live, perfectly dry, (see note below)	59.3
Oak, Red, Black, perfectly dry	32 to 45
Petroleum	54.8
Pitch	71.7
Poplar, dry (see note below)	29
Platinum	1342
Quartz	165
Rosin	68.6
Salt, coarse, (per struck bushel, Syracuse, N. Y., 56 pounds)	45
Sand, of pure quartz, perfectly dry and loose	90 to 106
Sand, of pure quartz, voids full of water	118 to 129
Sand, of pure quartz, very large and small grains, dry	117
Sandstone	151
Sandstone, quarried and piled, 1 measure solid makes $1\frac{3}{4}$ (about) piled	86
Snow, fresh fallen	5 to 12
Snow, moistened, compacted by rain	15 to 50
Sycamore, perfectly dry (see note below)	37
Shales, red or black	162
Silver	655
Slate	175
Soapstone	170
Steel	490
Sulphur	125
Tallow	58.6
Tar	62.355
Tin, cast	459

TABLE 17.—*Continued.*

WEIGHTS OF VARIOUS SUBSTANCES.

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Borometer 30 Inches. Weight of One Cubic Faat, 62-355 Pounds.	Average Weight of One Cubic Foot, Pounds.
Walnut, Black, perfectly dry (see note below)	38
Water, pure rain, distilled, at 32 degrees F., Bar. 30 inches.	62.417
Water, pure rain, distilled, at 62 degrees F., Bar. 30 inches ..	62.355
Water, pure rain, distilled, at 212 degrees F., Bar. 30 inches..	59.7
Water, sea	64.08
Zinc or spelter	437.5

"Cambria Steel," prepared by George E. Thackray, C. E.

NOTE.—Green timbers usually weigh from one-fifth to nearly one-half more than dry; ordinary building timbers, tolerably seasoned, one-sixth more.

TABLE 18.

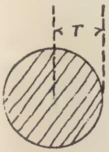
Values of B for use in column formulas.

Gray Iron	Wrought Iron	Structural or Open hearth steel	Crucible Machine Steel	Timber
$\frac{1}{6400}$	$\frac{1}{36000}$	$\frac{1}{22000}$	$\frac{1}{14000}$	$\frac{1}{3000}$

From Carpenter's Mechanics of Engineering. Wiley and Son's N. Y.

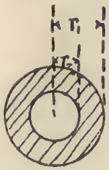
TABLE 19.

· Formulas for Polar Moment of Inertia (I_p). From "Mechanics of Engineering" by I. P. Church, C. E. John Wiley and Sons, N. Y. City.



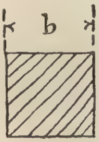
For a solid circular shaft.

$$I_p = \frac{\pi r^4}{2}$$



For a hollow circular shaft.

$$I_p = \tfrac{1}{2}\pi(r_1{}^4 - r_2{}^4)$$



For a solid square shaft.

$$I_p = \tfrac{1}{6}b^4$$

TABLE 19 A.

Table giving average values of floor load in pounds per sq. ft. for particular classes of buildings: Approximate,

Rooms in dwelling houses and schools	50
Offices	75
Garages, stables and foot bridges	70
Shops and store rooms	120 to 150

TABLE 20.

Giving approximate strength of hemp rope. Diameters approximate.

Diam.	Circumference	Ultimate strength in lb.
$\frac{7}{8}''$	$2\frac{3}{4}''$	4000
$1\frac{1}{4}''$	$3\frac{3}{4}''$	8000
$1\frac{1}{2}''$	$4\frac{1}{2}''$	12000
$1\frac{3}{4}''$	$5\frac{1}{2}''$	16000
$2''$	$6''$	20000
$2\frac{1}{4}''$	$7''$	28000

Cotton rope about two-thirds as strong as hemp.

Manila rope about 50 per cent. *stronger* than hemp rope.

TABLE 20 A.

Resumé of general notations used in formulas.

$H.P.$ .... Horse power.
M_s .... Simple moment.
M_b .... Bending moment.
M_B .... Maximum bending moment.
M_r .... Resisting moment.
$N=$ .... Rev. per minute.
P_t .... Total uniform load.
P_u .... A unit load.
L_i .... Length in inches.
L_f .... Length in feet.
S_u .... Unit fiber stress as used in beam and column formula.
I .... Rectangular moment of inertia.
I_p .... Polar moment of inertia.
c_n .... Distance from neutral axis to outer fiber of an element.

TABLE. 20 A.—*Continued.*

P_c...........A concentrated load.
P_e...........An eccentric load.
R...........A reaction.
R_s...........A resultant.
S_s...........Safe unit fiber stress in shear.
W...........Width in inches.
V...........Surface speed in feet per min.
A_c...........Arc of contact in degrees.
r...........Radius of gyration.
P_m...........A combined load treated as a single load.
S_k...........Safe fiber stress in direct tension or comp. in eccentric column formula.
d...........Distance of resultant of loads from column center.
A...........Sectional area in sq. ins.
r_s........... Radius of a shaft.

TABLE 21.

Shafting Speeds.

Iron working shops........................150 R. P. M.
Wood working plants.....................275 R. P. M.
Clothing factories and cloth mills in general.350 R. P. M.

TABLE 21 A.

Horse-power required for various machines, average values.

Machine	H. P.	
20″ Engine lathe	½	for metal turning.
15″ Stroke shaper	¾	for metal planing.
36″ 11 ft. stroke planer	1	for metal planing.
Drill press; capacity from ¼″ to 1″ drill	1¼	for metal work.
10″ Stroke slotter	½	for metal work.
Brown and Sharpe milling machine No. 1	¼	for metal work.
20″ Swing horizontal boring mill	1	for metal work.
24″ Planer	3	for wood work.

TABLE 21 A.—*Continued.*

Saw bench carrying a saw 23″ diam.	$3\frac{1}{4}$	for wood work.
Band saw, 34″ wheel	1	for wood work.
Grindstone	$1\frac{1}{2}$	for general use.
Emery wheel	1	for general use.

Adapted from Kent's Engineer's Pocket Book. Wiley and Sons, N. Y.

TABLE 21 B.

Holding power of lag. screws.

Diam. of screw	Diam. of bit used to bore hole	Length of thread screwed in wood	Load at which screw pulled out
$\frac{7}{8}''$	$\frac{5}{8}''$	$3''$	5900#
$\frac{7}{8}''$	$\frac{11}{16}''$	$3''$	5900#
$\frac{7}{8}''$	$\frac{3}{4}''$	$3''$	6000#
$\frac{7}{8}''$	$\frac{3}{4}''$	$5''$	9000#
$\frac{3}{4}''$	$\frac{5}{8}''$	$4\frac{1}{2}''$	7000#
$\frac{5}{8}''$	$\frac{1}{2}''$	$4''$	6000#
$\frac{1}{2}''$	$\frac{3}{8}''$	$3\frac{1}{2}''$	3500#
$\frac{3}{8}''$	$\frac{5}{16}''$	$2''$	1900#
$\frac{1}{4}''$	$\frac{3}{16}''$	$1''$	700#

TABLE 22.

From Hutton's Mech. Eng. of Power Plants. Relation between thickness of plate, diameter of rivet and diameter of hole for riveted joints.

Thickness of plate.........	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
Diam. of rivet............	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$
Diam. of hole.............	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$

TABLE 23.

Weight of electrical machinery.

Motor H. P.	Dynamo K. W.	Weight
100	90	11000
75	60	6500
50	45	4500
35	31½	3350
25	22½	2400
15	13	1510
10	10	920
7½	7½	760
5	5	510
3	3	410

From Kent's Engineer's Pocket Book. Wiley and Sons, N. Y.

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